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Abstract

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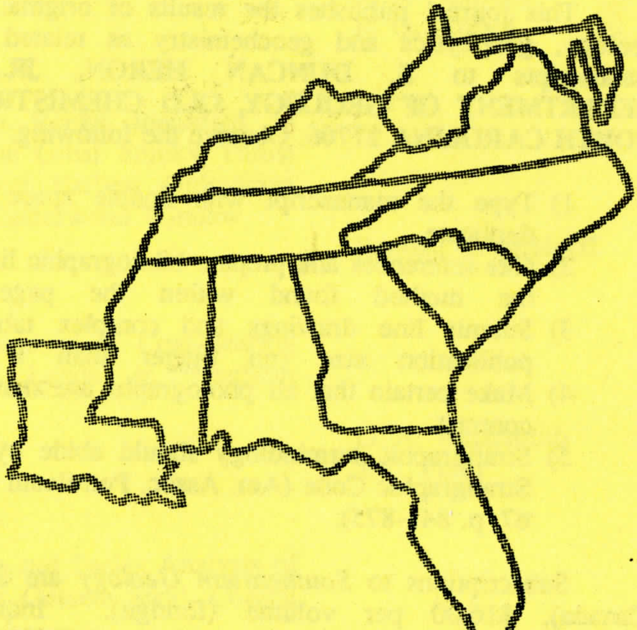

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CHLORITIZATION OF DOLOSTONE: POSSIBLE SOURCE OF SILICA FOR TALC FORMATION

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ABSTRACT

Chlorite-bearing rock and residuum have been noted to be closely associated with talc near Winterboro, Alabama. Large areas, up to 60 contiguous acres at one site, consist of chlorite ± quartz produced by the replacement of feldspar, layer silicates and quartz in argillaceous rocks and in dolostone by Mg-chlorite. The IIb chlorites vary in composition and may be classified as clinochlores, sheridanites or penninites. Sedimentary strata, varying from partly to completely chloritized, show no changes in width demonstrating that the replacement is essentially volume-for-volume. While some silica may come from chloritized shale and siltstone, much or most of the silica necessary to produce talc may have come from chloritization which is not obvious because it involved the silica and silicates occurring in amounts of 3% or less in dolostone of the region. However, the large volumes of altered rock compensate for the small percentage of minerals per unit volume. Excess silica resulting from such replacements is proposed as the source of the silica to produce talc in favorable areas of dolostone originally deficient in silica.

INTRODUCTION

The talc deposits near Winterboro, Alabama, are unique because they are associated with dolostone which is essentially unmetamorphosed. The talc formed in dolostone through the agency of magnesium-bearing hydrothermal fluids; associated rocks and clay minerals, within the dolomite rock, were altered to Mg-chlorites. The transformation of shale or quartz and silicates in dolostone to chlorite would have released SiO_2 which could have migrated into favorable areas of the carbonate rock to produce talc. The dolostone in this area contains less than 3% insoluble minerals, certainly insufficient silica to produce talc without addition of silica. In earlier reports chloritization was suggested as an important and

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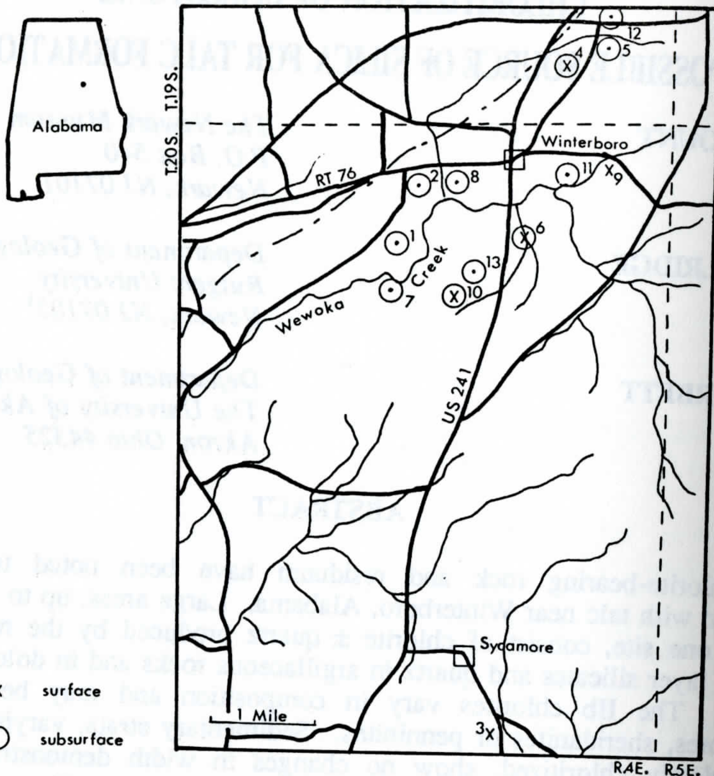


Figure 1. Sites of surface (exposed rock) and subsurface (indicated by soil) chloritization in the Winterboro area. For more details of each site see Table 1. See text for a discussion of the significance of the southwest to northeast dashed line.

necessary process in talc formation (Blount and Vassiliou, 1980; Blount and Helbig, 1987), but the extent of this associated feature was not known. The volume of chloritized shale or siltstone should exceed talc by about two and one half times according to this hypothesis. This paper reports on subsequent investigation of chloritization. Evidence of volume-for-volume replacement of argillaceous rocks and evidence supporting alteration over a sufficiently extensive area to be a source of silica for talc formation will be discussed. Questions still remain concerning details of plumbing of the mineralizing fluids and of the controls of mineralization. Our further work is unfortunately precluded by a change of personnel in the company possessing the exploration leases; however, the importance of the areally extensive alteration of a generally ignored fraction of dolostone and its association with talc mineralization is a feature which needs to be put on record. The significance of this feature may have been overlooked in other areas and so has implications beyond this single region.

GEOLOGY OF THE AREA

Rock composed primarily of Mg-chlorite occurs in association with talc bodies located about one-half mile west of Winterboro, Alabama (Figure 1 and

Table 1. Nature of parent rock and area of chloritization for sites shown in Figure 1.

No.	Altered rock	Talc	Rock*	Area altered	Comments	No. of holes auger/core
1	shale and dolomite	X	yes	>1800 ft. from talc body (58 acres)	south talc body	367/34**
2	dolomite	X	no	unknown	north talc body	93
3	shale and siltstone	X	yes	road cut, extent unknown	talc in rock	
4	shale	X	yes	>0.5 acre	talc in soil	32
5	dolomite	X	yes	>5 acres	talc in rock and in soil	21/7
6	dolomite	X	yes	>60 acres	talc in rock and in soil	232/51
7	dolomite	X	no	>5 acres	talc in soil	42
8	shale (?), shaly dolomite	X	no	>12 acres	talc in soil	72
9	shale, siltstone	X	yes	road cut, extent unknown	trace talc in rock	
10	shale, dolomite	X	yes		talc in soil	49/2
11	dolomite		yes	water-well cuttings	cuttings, no talc detected	
12	shale (?)	X	no	600 ft. linearly along Rt. 16	talc in soil	69
13	dolomite	X	no	about 2 acres	talc in soil	69/14

* Yes indicates that rock was examined either from surface exposures or from core. No indicates that only soil was examined.

** Plus drill cores examined in original study (Blount and Vassiliou, 1980).

Table 1). Two talc bodies have been mined, these designated north and south bodies (site 2 and 1, Figure 1). The talc bodies are lens-shaped, thick at the center and thin at the edges. The south body dips about 60° northeast into the dolostone bedrock. The massive talc shows exact replication of the dolostone textures including stylolites. In the dolostone individual flakes and rosettes of talc can be seen projecting from fracture surfaces. These observations indicate volume-for-volume replacement of dolostone surrounding a fault or fracture opening. The north body is lens-shaped lying almost horizontal and is surrounded on all sides by clay. The clays remain from the weathering away by solution of previously existing dolostone. The north body may be associated with a fault or fracture parallel to that of the south body, but the thick cover of residuum and the altered position of the north body renders this relation unclear.

Drilling has shown the presence of chloritized siltstone and argillaceous rocks at approximately 200 ft. below the surface, at the down-dip end of the south body (Blount and Vassiliou, 1980; Blount and Helbig, 1987). The chlorite rock is gray-green, showing structure suggestive of stratification. The presence of silty layers up to several centimeters thick confirm this. X-ray diffraction has shown only chlorite and quartz to be present in this rock, but microscopic examination shows pyrite in addition. The presence of chloritized rock can be inferred for the north body from the residuum rich in chlorite which surrounds the talc body. This will be described in more detail below.

Over a larger region, the Winterboro area consists of broad valleys bordered by northeast-southwest trending ridges rising about 200 ft. above the valley floors. The valleys are generally underlain by dolostone and the ridges by sandstone, siltstone and shale. These rocks exhibit weak to very low-grade metamorphism as determined from the degree of crystallinity of the illites analyzed by X-ray diffraction (Blount and Helbig, 1987). Within this setting a number of sites showing chloritized shales and siltstones have been noted and even larger areas of subsurface chloritization are present.

EXPERIMENTAL

Two types of material were utilized in this investigation: residuum (soil) samples and bedrock samples. Except for a few samples obtained from rock exposures and road cuts, the vast majority of both types of samples were obtained by drilling. A sample was collected at each 6 ft. interval during auger drilling. The holes were 3 inches in diameter. This drilling probably allows some contamination from shallower residuum in samples representing deeper intervals.

These 6 ft. composite samples were analyzed using standard X-ray diffraction techniques for clay minerals. Routine runs used sedimented samples, of less than 4 micron particle size, on glass slides. Glycolations and heat treatments were used as needed for specific identifications. When bulk samples were analyzed they were prepared by wet grinding in a McCrone micronizing mill and by slurrying onto a glass slide.

Core samples were obtained of the bedrock encountered in some auger drill holes. A portable core drill was used to obtain a rock sample one inch in diameter and 3 to 6 inches long. Where bedrock was deeper than 65 ft., a core could not be obtained with this drill. The carbonate rocks were analyzed for carbonate type and for insoluble minerals. The calcite to dolomite ratio was determined by XRD using the method of Tennant and Berger (1957). The insoluble residue was obtained by dissolving ten grams of sample in 1N HCl. The resulting insoluble residue was ground to a uniform particle size and analyzed by X-ray diffraction. Insoluble residues containing large amounts of iron oxides were cleaned before analysis according to the method of Jackson (1979). The percent of insoluble material in the carbonate rock was determined by weighing the dry sample before and after acid treatment.

Over 4000 residuum samples representing about 1000 holes were analyzed during the course of this investigation. Also incorporated are results obtained by Helbig (1983) during an earlier study. In addition, 140 core samples and samples obtained from outcrops and road cuts were analyzed.

The composition of selected chlorite samples was determined by use of optical parameters by the method of Hey (1954) and X-ray parameters by the methods of Brindley and Gillery (1956) and Bailey (1972). The validity of these methods is demonstrated by the results obtained in cases where wet chemical analysis has also been done (Blount and Helbig, 1987).

DIRECT EVIDENCE OF CHLORITE ALTERATION

Both argillaceous rocks and dolostone have been chloritized. In both cases this alteration is not obvious, and generally X-ray diffraction is needed to confirm the mineralogy because of the fine grained nature of this chlorite. Further, with the dolostone only the original quartz and silicates have been altered. Identification of the minerals present in altered carbonate rock, generally being present at the 3% level or less, requires acid digestion of the carbonate and subsequent X-ray analysis.

Chloritized argillaceous rock is exposed at the surface in four known sites (3, 4, 9 and 10, Figure 1). The surface occurrences attracted notice because weathered chlorite rock exhibits a very light gray color, is non-gritty and has a good "slip". The X-ray analysis of the material shows it to be almost pure chlorite. The term "chlorite rock" or chloritite will be used herein to denote this material. This non-gritty chlorite rock was originally shale. Interbedded layers show sand and silt grains in a chlorite matrix. Detailed descriptions of these rocks can be found in Blount and Vassiliou (1980) and Blount and Helbig (1987).

The chloritized dolostone shows no features in hand sample or thin section to indicate alteration. The acid insolubles, however, when analyzed by X-ray diffraction show chlorite with varying amounts of quartz (19-R and 13-R of Fig-

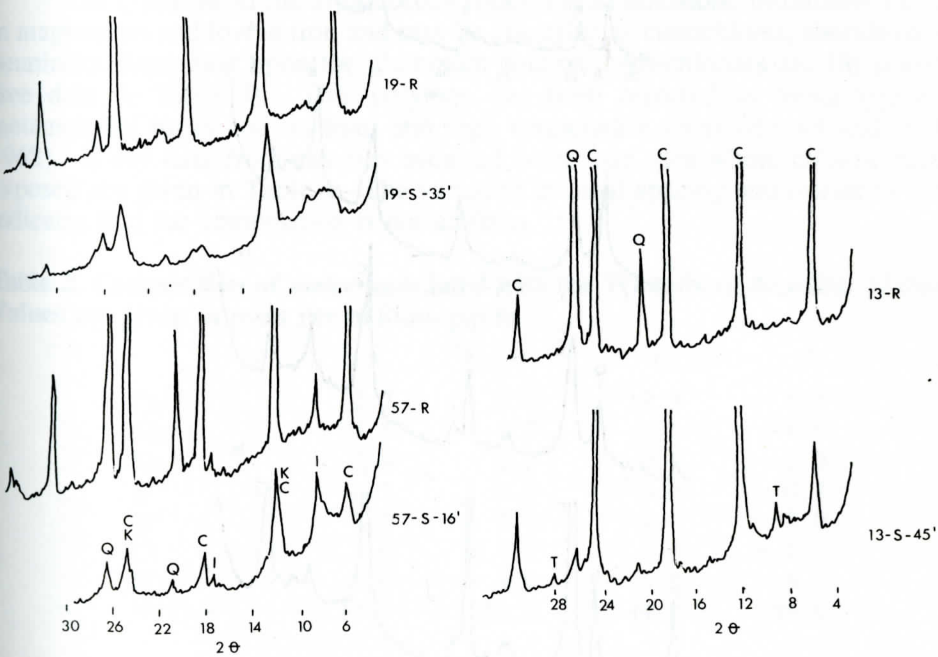


Figure 2. X-ray diffraction patterns of acid insoluble residues of dolomite bedrock (labeled R) and of residuum directly overlying the bedrock (labeled S) for locations at site 6. Depth indicated for residuum. Peaks marked T are talc peaks, C are chlorite peaks, K are kaolinite peaks, I are illite peaks and Q are quartz peaks.

ure 2). Incomplete alteration of the layer silicates is also demonstrated by the presence of small amounts of illite in some samples (57-R of Figure 2). The samples illustrated were selected to show the range of mineral quantities, particularly of quartz and illite. Typically insoluble residues of altered dolostone contain 10 to 25% quartz and zero to 10% illite. Unaltered dolostone in this area has acid insoluble residues consisting of illite, quartz and feldspar (plagioclase and K- feldspar) ± minor chlorite. The insoluble residues average 60% quartz, 23% illite and 16% feldspar. Feldspars are absent in highly altered dolostone, and evidence from partly altered carbonates indicates that chloritization of feldspars commenced before the chloritization of illite. Because of the fine grained nature of these minerals it is not possible to determine if feldspar altered through an intermediate mica (illite) stage as has been suggested by others (Moine and others, 1982).

RESIDUUM, INDIRECT EVIDENCE OF CHLORITE ALTERATION

The residuum overlying the bedrock is deep in most locations in the Winterboro area. Auger drilling of these soils shows generally depths of 30 to 70 ft. to bedrock. X-ray analysis of the clays acquired by drilling shows the frequent

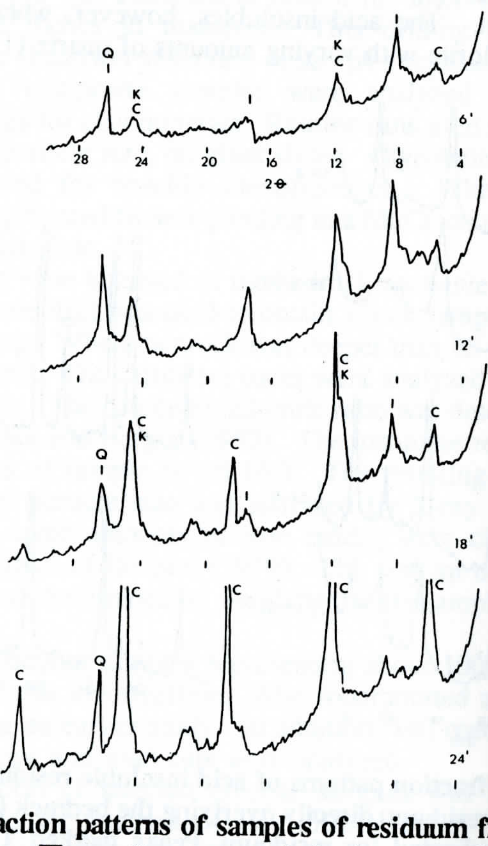


Figure 3. X-ray diffraction patterns of samples of residuum from depths indicated in a single bore hole. The patterns are of the less-than-four micron fraction. Symbols are the same as indicated for Figure 2.

and wide-spread occurrence of chlorite. Examples of X-ray diffraction patterns from soils are shown in Figure 2 along with the X-ray diffraction patterns of the acid insoluble residues from the parent rock, samples of which were acquired by core drilling in the same hole as the soil boring. The chlorite from the parent rocks is broken down by weathering to kaolinite (see 19-S of Figure 2). Figure 3 shows the sequence within a single drill hole. Near the surface the kaolinite peaks predominate and the chlorite peaks become very weak. Chemistry of stream and ground water in the area of the talc deposits indicates that chlorite and illite should alter to kaolinite with sufficient time (Table 2).

Locations indicated by circles in Figure 1 show chlorite in the soil in amounts greater than 50%. From this we deduce that the bedrock is chloritized. In many cases both soil and rock have been obtained by drilling confirming this association. Chlorite-rich soils occur over chloritized argillaceous rocks and over dolostone with chloritized insolubles. Large areas are underlain by such chloritized rock. In most sites the total area of altered rock has not been completely determined because the drilling has not encountered unaltered rock on all sides of the area of drilling. This is true of location 6 (see Figure 1), for example, where greater than 60 acres is underlain by chlorite soils and chloritized rock.

NATURE OF CHLORITES

The chlorites in the argillaceous rocks and in dolostone insolubles are high in magnesium and low in iron and may be classified as clinochlores, sheridanites or penninites depending upon the aluminum content. All chlorites are IIb polytype (see data in Table 3). This polytype has been reported as being typical of metamorphic rocks and medium and high temperature veins (Brown and Bailey, 1962). X-ray data from samples acquired from four sites where chlorite rock is exposed are given in Table 4. The variation in basal spacing and refractive index indicates that the composition is not uniform.

Table 2. Composition of water associated with the Winterboro deposits, Alabama. Values are given in parts per million, p.p.m.

	A	B	C	D
Ca^{2+}	2.2	9.4	8.3	8.5
Mg^{2+}	1.5	4.2	5.6	4.9
Na^{+}	0.4	1.0	0.4	1.0
K^{+}	0.7	0.8	0.5	0.7
Si^{4+}	2.0	2.0	2.0	2.0
Cl^{-}	< 1.0	< 1.0	< 1.0	< 1.0
SO_4^{2-}	7.0	6.0	5.0	5.0
HCO_3^{2-}	12.0	42.0	44.0	48.0
pH	6.5	7.2	7.2	7.0

A north pit; B south pit; C stream near north pit; and D stream near south pit.

Talc is associated with areas of chloritization as indicated on Table 1. Where chloritization extends over a sizeable area, only some of the soil and bedrock samples have a showing of talc. Although the amount is generally only a few percent, it is enough to show the close genetic association of Mg-chlorite and talc in this area. A previous study of the insoluble residues of dolostone from the alteration halo surrounding the south body showed talc, chlorite and quartz. The proportion of talc to chlorite and quartz increased in samples nearer to the talc body (Blount and Vassiliou, 1980). At the time of that study, the extent of alteration of dolostone was not known. In addition, it was not known what alteration minerals would be found beyond the talc-chlorite-quartz zone, because samples had only been obtained within 200 ft. of the south body by drilling. Extrapolation indicated that the amount of talc should fall to zero by 300 ft. from the body. More recent work has shown the talc-chlorite-quartz zone is surrounded by a zone composed primarily of chlorite and quartz + minor illite and/or talc, which in turn grades into a zone in which illite predominates in the acid insolubles of the dolostone. The chlorite-quartz zone extends through very large volumes of dolostone (expressed in the large areas of altered bedrock dolostone and overlying chloritic soils). Table 5 shows the nature of the acid insoluble residues in bedrock dolostone to a distance as great as 1800 ft. from the south talc body. Although the amount of illite has increased to about 25% in samples at 1500 ft., the chlorite values are still high. This is still by no means a typical unaltered dolostone.

VOLUME-FOR-VOLUME REPLACEMENT

At one site (no. 3, Figure 1), the exposed argillaceous rocks have been noted in a partly altered condition. This is particularly instructive because it demonstrates the process of chloritization by preserving intermediate stages. Samples were carefully taken along strata which appeared to vary from partly to completely altered. Data from three such sets are shown in Table 6. One sample of each pair is highly altered, with sample 7b being almost completely altered to chlorite. A very notable feature of this exposed rock is that the strata retain a constant width even where highly altered (Figure 4), demonstrating volume-for-volume replacement has occurred.

In earlier reports (Blount and Vassiliou, 1980; Blount and Helbig, 1987), we had suggested that aluminum remained constant during this transformation. This deduction was based on the observation that a completely chloritized rock from site 4 (see Figure 1) contained 16.4% Al_2O_3 (Blount and Helbig, 1987) and that a typical argillaceous rock contains 15-18% Al_2O_3 (Weaver, 1984; Mason, 1959). The mineralogy and chemical composition reported here, however, demonstrate that aluminum is somewhat moble during the replacement process. Calculating both on oxide percentages and on numbers of aluminum ions per constant volume, the aluminum is higher in the more altered rocks than in the partly altered rock (Figure 5). Conversely, the silica content is lower in the final chloritized rock.

From the mineralogy of these samples, as well as of a large number of acid insoluble residues, the minerals appear to have been altered in the following sequence. Feldspar is the first mineral to completely disappear. (The Al_2O_3 content of feldspar and chlorite are about equal.) This is followed by illite and finally by quartz. Because illite contains more of aluminum than chlorite, the hydrothermal fluids must become enriched in aluminum during the transformation of illite to chlorite. The presence of aluminum in the solutions during the final alteration of quartz would explain why talc did not form in these rocks from the reaction of quartz with magnesium-bearing solutions.

Figure 4. Two samples were obtained from this area of exposed rock (see Table 6 samples 7a and 7b). The strata are inclined from the upper right to the lower left corner of the photograph. The rock at the right side of the photograph is almost pure chlorite and at the left is illite, chlorite, quartz and feldspar. A distinct change from tan (left) to gray (right) along a vertical line dividing the photograph (near the hammer point) marks the boundary of mineralogy.

DISCUSSION

Chloritization has occurred at a number of sites in the Winterboro area and affected varying volumes of rock. The clustering of identified sites near the north and south talc bodies probably results from that area having been more carefully examined than the other areas. Subsurface chloritization is not easily observed because it requires samples from deep in the residuum. Supplementary bedrock samples serve to confirm such identifications. These samples once acquired require preparation and X-ray analysis. This has been done at only a few sites between sites 3 and 10 (see Figure 1), so that the gap there is probably not of any particular significance. In general, however, the rocks to the south show less complete alteration than those near the known talc deposits. In the area to the west of the dashed line shown in Figure 1, no indication of chloritizations has been found, although it has been sought. This boundary may, therefore, have some significance.

In the previous section, a progression of alteration based on evidence from analysis of argillaceous rocks and insolubles was proposed. At site 3, samples are

Table 3. X-ray data. Chastain chlorite (site 9).

hkl	d	I
001	14.07 Å	8
002	7.06	10
003	4.73	8
00,11	4.58	4
004	3.54	9
005	2.84	2
202	2.56	4
201	2.52	9
203	2.42	7
202	2.37	3
204	2.24	3
205	2.06	1
204	1.99	6
206	1.87	2
205	1.82	2

Table 4. X-ray* and optical data for Winterboro chlorites.

	Site 9	Site 4	Site 3	Site 6
hkl	I	I	I	I
001	9	10	9	8
002	10	10	10	10
003	7	7	6	8
004	7	7	8	8
005	2	2	2	2
basal spacing (Å)	14.18	14.19	14.21	14.19
refractive index	1.570	1.576	1.587	
LOI (%)	13.5	12.5	12.3	

* samples in preferred orientation.

all altered at least to some extent so that an original composition can only be deduced. From this the amount of silica which became available during the replacement process can be calculated (see Figure 5). The hypothetical starting composition is determined by assuming all of the layer silicates of the partly altered samples began as illite. If feldspar constituted a significant portion of the original argillaceous rock, then the original aluminum content of the rock would have been slightly lower and the silica content slightly higher than shown. Silica is released during the alteration, and even in those cases where significant quartz remains in the final chloritized rock (see samples 9 and 8, Table 6), 70% of the total possible silica which could be released was released during the replacement process.

Table 5. Mineral proportions (given in weight percent) of the acid insolubles from dolostone. Headings at the top of the columns indicate distance from the south body.

300-500 ft.				500-1000 ft.				1000-1500 ft.				>1500 ft.			
chl	qtz	ta	mi	chl	qtz	ta	mi	chl	qtz	ta	mi	chl	qtz	ta	mi
85	11	4		90	10			81	19				100		
82			18	38	62			100				55	17		25
10	90			88	6		6	93			7	76			24
77	20	3		79	8		12	81	19						
9	87	4		100				85	13		2				
	100			100				55	7	6	32				
65	33	2		59	41			43	52	5					
				29	71										
				95	5										
				81	5		14								
				63	25		11								
				89	tr		11								

chl = chlorite. qtz = quartz. ta = talc and mi = illite

Where volume-for-volume transformation is complete, 2.4 volumes of argillaceous rock would yield enough silica to form one volume of talc. On this basis the suggestion was made (Blount and Helbig, 1987) that, although the magnesium has been brought in with hydrothermal solutions, the silica could be locally derived. To estimate an amount of silica available for talc formation, site 6 (see Fig. 1) will be taken as an example. The bedrock over 60 acres is chloritized and the soils are primarily chlorite (or weathered chlorite) for at least 6 to 18 feet above the bedrock surface. This involved 3.2×10^7 ft^3 of chloritized material assuming a 12 ft. thickness of chlorite soil. Even if only 35% of the possible silica was released during chloritization (instead of 70% as above), this would yield more than enough silica to form a body the size of the north talc body (Blount and Vassiliou, 1980). Using 35% alteration, 6.9 volumes of chlorite could yield one volume of talc; thus, 3.2×10^7 ft^3 of chlorite in the soil would yield 4.6×106 ft^3 of talc. No correction is made for density as the density of the north body talc and the density of the chlorite soils are about equal (Blount and Helbig, 1987). We are not suggesting that site 6 is the actual source of the silica for the formation of the north body, but that, if the present erosion surface is typical of the entire volume of these rocks, chloritization is more than adequate to have supplied the silica for the talc bodies which have been discovered and others yet undiscovered. It should be noted, moreover, that the bedrock at site 6 is dolostone and that the weathering of dolostone has yielded this very great thickness of chlorite residuum.

Another way to examine the availability of silica from chloritization of insoluble minerals in dolostone is to calculate the size of a sphere of altered rock which would have to surround a mass of talc 5×10^6 ft^3 and to compare this with values shown on Table 5 for the south body. As indicated previously the insoluble residues have compositions typical of argillaceous rocks so that one may

Table 6. Mineralogy of argillaceous rocks exposed at site #3. Pairs (labeled a and b) indicate rocks along a given stratagraphic layer (see Figure 4). Chemical composition is given for samples 7a and 7b.

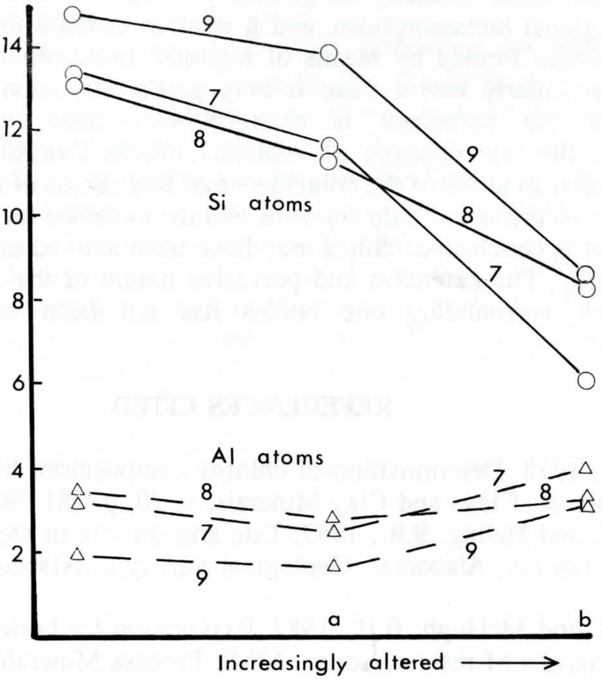
no.	less altered	no.	more altered
9a	16% chlorite 16% illite 60% quartz 8% feldspar (K-feldspar and plagioclase) density = 2.62	9b	78% chlorite 22% quartz density = 2.65
8a	35% chlorite 17% illite 37% quartz 10% feldspar (plagioclase) density = 2.60	8b	79% chlorite 18% quartz 2% talc 2% illite density = 2.68
7a	28% chlorite 50% quartz 17% illite 5% feldspar (plagioclase) density = 2.53	7b	98% chlorite 2% quartz density = 2.51
	SiO_2 69.7% MgO 7.6 Al_2O_3 10.7 Fe_2O_3 1.4 FeO 1.4 CaO 0.039 LOI 4.9		SiO_2 34.4% MgO 25.3 Al_2O_3 19.6 Fe_2O_3 1.8 FeO 3.7 CaO 0.034 LOI 12.0

Chemical analyses by Skyline Laboratories, Wheat Ridge, CO.

extrapolate the availability of silica from values shown for rocks at site 3 (previous section). Actual experimental values show the amount of insoluble minerals in the dolostone is 1.5% near the south body (to 1000 ft.). Using this value and 35% alteration as shown above, a sphere of 820 ft. radius of dolostone with 1.5% insoluble minerals would yield enough silica for 5×10^6 ft^3 talc. The values shown in Table 5 indicate that the extent of alteration is greater than 820 ft. and that the degree of alteration is greater than 35% (calculated value: 78% altered).

In summary, field evidence indicates that chloritization of argillaceous rocks is a volume-for-volume replacement process. Therefore, one can make a prediction about the amount of SiO_2 which was released from the rock resulting from this transformation. Both shales/siltstones and insoluble minerals in dolostone have been altered in this way; however, the extent of chloritization of the dolostone exceeds what we had expected and it appears that the dolostone may be a more significant source of silica than chloritized shale/siltstone. Certainly at the

Figure 5. Numbers of silicon and aluminum atoms in 692 $Å^3$ of variously altered argillaceous rocks (site 3). Values at the left were determined for a theoretical starting mineralogy as described in the text. Table 6 shows further details of these samples.



two sites discussed there is sufficient chloritization at each to produce enough silica to form a deposit the size of the north body. Chloritized dolostone occurs at a number of other sites where the total extent is less well determined than at the two sites which were used as examples.

Although such calculations cannot prove that the formation of talc necessarily involves the simultaneous formation of chlorite, the finding of chlorite in the abundance predicted by earlier theoretical considerations lends credence to the theory that the two are intimately associated. Other investigators have noted the close association of talc with chlorites. The economically significant talc of Tremouns, France is an example. Fortuné and others (1980) suggested that the chloritization of mica-schist and pegmatite provided silica for the formation of talc there. More recently, Moine (1982) and Moine and others (1982) have emphasized this association but suggested that talcite and chloritite are metasomatic alteration zones produced by hydrothermal solutions high in chloride. The source of silica would not present a problem in this case because silica and silicate minerals are quite soluble in such solutions and quartz-bearing rocks are abundant in the environment.

The point to emphasize is that "dispersed" chlorite in dolomite rock is an important feature associated with hydrothermally-formed talc deposits, regardless of whether the chlorite represents a source of silica or a dispersed metasomatic zone such as that proposed by Moine (1982). In the United States, large volumes of chloritized carbonate rock are found to occur with talc in Montana (Blount and

McHugh, 1987 and Nelridge, 1987) and North Carolina (Blount and others, 1983) in addition to Alabama. The presence of such chloritization is easily overlooked when rock is examined by standard petrographic methods. Indeed, chlorite is a mineral which might normally be present in certain amounts from prograde or retrograde regional metamorphism, and it is often difficult to ascertain whether a particular chlorite formed by means of regional metamorphism or hydrothermal alteration, particularly where there is only partial alteration. Further, the bulk chemistry of the carbonate is changed very little during chloritization. Nevertheless, the talc deposits of Alabama, North Carolina and Montana are strikingly similar in terms of the coincidence of large areas of chloritized carbonate rock with the occurrence of talc deposits, and the evidence for hydrothermal origin of the chlorite is conclusive. Silica may have been derived in all these areas from local alteration. The extensive and pervasive nature of the chlorite dispersed in dolomite rock surrounding talc bodies has not been recognized by other investigators.

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OLDEST KNOX GROUP ROCKS IDENTIFIED IN WINDOWS THROUGH THE GREAT SMOKY THRUST SHEET, EAST TENNESSEE: EARLIEST ORDOVICIAN CONODONTS FROM THE CALDERWOOD WINDOW

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ABSTRACT

Conodonts from carbonate rocks of the Calderwood window, Great Smoky Mountains, Tennessee, demonstrate that rocks mapped as Jonesboro Limestone in this window are equivalent to the Chepultepec Dolomite and possibly the upper Conococheague Limestone of the Valley and Ridge province to the north, west, and northwest. Four samples from various localities in the window yielded conodonts representative of the *Cordylodus proavus* Zone to the *Rossodus manitouensis* Zone, indicating an earliest Ordovician age for these rocks. Previous reports speculated that these rocks were Longview Dolomite or Kingsport Formation equivalents as were Jonesboro rocks from other windows in this region. These lowest Ordovician rocks of the Calderwood window are the oldest documented Knox Group carbonates exposed in structural windows through the Great Smoky thrust sheet in east Tennessee.

INTRODUCTION

The Calderwood window is the southwesternmost structural window in the Great Smoky thrust sheet in central-east Tennessee (Fig. 1). These windows expose Lower and Middle Ordovician carbonate and clastic rocks that can be correlated with rock units of the Valley and Ridge province to the northwest and provide the opportunity to examine Valley and Ridge rocks beneath the Blue Ridge province. Lithostratigraphic and paleontological studies of the Ordovician rocks in the three larger windows northeast of the Calderwood window (Wear Cove window, Tuckaleechee Cove window, and Cades Cove window) permitted their correlation with Valley and Ridge province rock units (Neuman and Nelson, 1965). However, rocks in the Calderwood window have only been assigned as part of the great thickness of Knox Group rocks. Previous fossil data have not been biostratigraphically diagnostic.

During studies of conodont color alteration in central-east Tennessee (Harris and others, 1978; Orndorff and others, 1988) carbonate rock samples were collected from the four windows through the Great Smoky thrust sheet shown in Figure 1. Most of these samples yielded sufficient conodonts to determine zonal or faunal interval assignments. Samples were collected from four widely scattered localities in the Calderwood window. Each locality could be zoned, and therefore provides a basis for correlation to Valley and Ridge province rocks to the northwest.

The Calderwood window is within the Great Smoky Mountains of east Tennessee, mostly in Blount County, but with a small part across Chilhowee Lake in

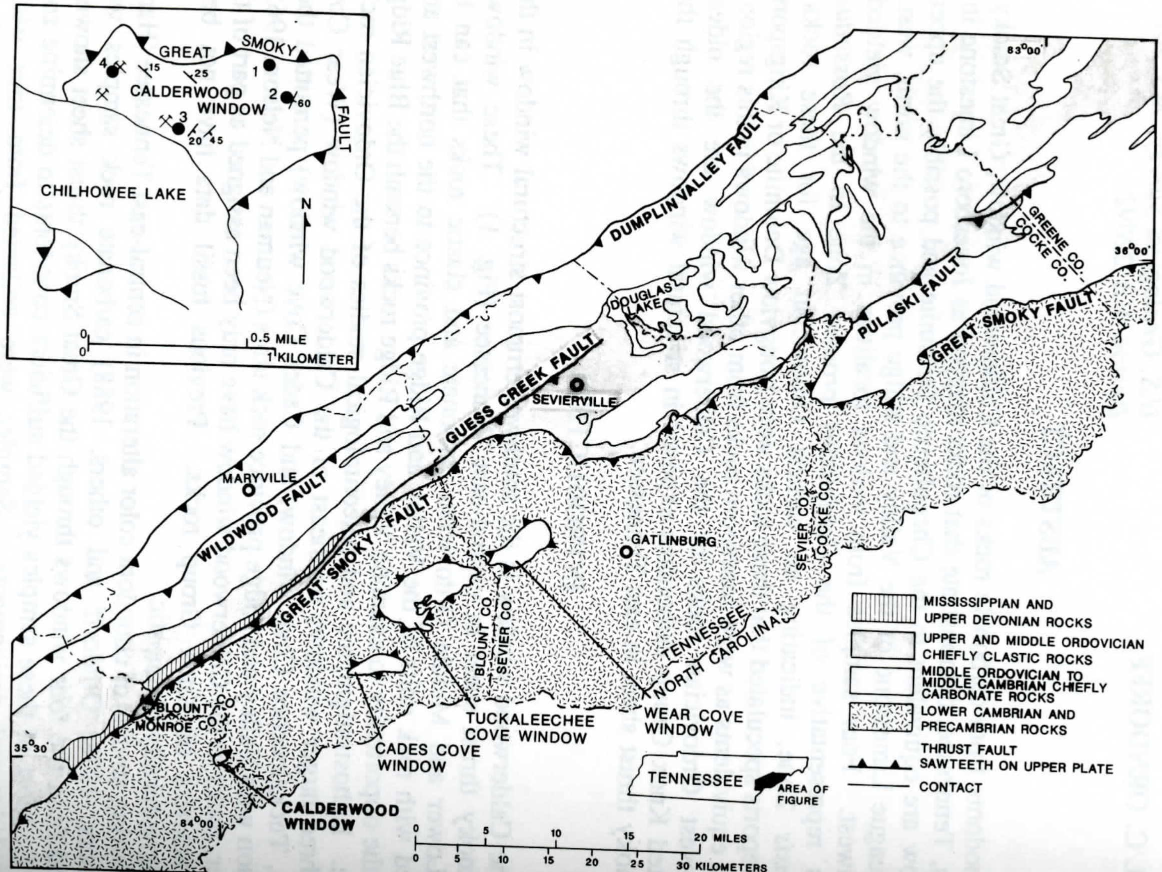

Figure 1. Generalized geologic map of central-east Tennessee (geology modified from Hardeman, 1966) and map of the Calderwood window showing sample localities (Sample 1, 10452-CO; Sample 2, 10451-CO; Sample 3, 10575-CO; Sample 4, 10576-CO).

Monroe County (Fig. 1); the window is approximately 1.5 km^2 in area. In comparison with the other windows of this region, Wear Cove window is 15 km^2, Tuckaleechee Cove window is 37 km^2, and Cades Cove is 10 km^2. The window is surrounded by Precambrian and Cambrian sedimentary and metasedimentary rocks of the Great Smoky thrust sheet. Rocks within the Calderwood window are very near the Great Smoky thrust fault and therefore are structurally complicated. Folds, faults, and calcite-filled fractures are common and make it difficult to produce substantial stratigraphic sections.

STRATIGRAPHY

The rocks and structures of the Calderwood window and the other windows of this area were described by Neuman and Nelson (1965). Rocks from the upper part of the Lower Ordovician Jonesboro Limestone through the Middle Ordovician Blockhouse Shale occur in both the Wear Cove and Tuckaleechee Cove windows, but only the middle or lower part of the Jonesboro Limestone was reported for the Cades Cove window. Macrofossils were used to date and correlate these rocks to the Valley and Ridge province and indicated that the Jonesboro Limestone of Cades Cove was equivalent to the Longview Dolomite or Kingsport Formation. No biostratigraphically diagnostic fossils were found in the Jonesboro of the Calderwood window.

<table>
<tr><th>GROUP</th><th colspan="2">NORTHWESTERN AREA</th><th>SOUTHEASTERN AREA</th></tr>
<tr><td rowspan="5">KNOX GROUP</td><td colspan="2">MASCOT DOLOMITE</td><td rowspan="4">JONESBORO LIMESTONE</td></tr>
<tr><td>KINGSPORT FORMATION</td><td rowspan="2">KINGSPORT FORMATION OF HARRIS, 1969</td></tr>
<tr><td>LONGVIEW DOLOMITE</td></tr>
<tr><td colspan="2">CHEPULTEPEC DOLOMITE</td></tr>
<tr><td colspan="2">COPPER RIDGE DOLOMITE</td><td>CONOCOCHEAGUE LIMESTONE</td></tr>
</table>

Figure 2. Subdivisions of the Knox Group for east Tennessee (modified from Rodgers, 1953).

The Jonesboro Limestone is the southeastern limestone equivalent of the Valley and Ridge carbonate sequence of Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite (Rodgers, 1953; Neuman and Nelson, 1965) (Fig. 2). The reference section for the Jonesboro Limestone is in the eastern Valley and Ridge of Tennessee, along Jockey Creek, near Greenville, Greene County, Tennessee (Oder, 1934). The Jonesboro has been compared with the Knox Group rocks of the northwestern thrust belts of east Tennessee by several workers. Rodgers (1953) was able to correlate several horizons within the Jonesboro with horizons in the Knox Group to the northwest; however, he was unable to locate contacts for the Knox Group formations that might be contained within the Jonesboro. Furthermore, the concept of the Longview Dolomite was in question until Harris (1969) proposed dropping it as a formation due to the lack of well-defined upper and lower contacts.

The Jonesboro Limestone of the Pulaski thrust sheet is dominantly limestone; however, at some localities it contains greater than 10 percent dolostone (see measured section of Oder, 1934). Farther southeast, in the windows of the Great Smoky thrust sheet, small, tectonically repeated sections of the Jonesboro Limestone contain probably less than 10 percent dolostone (Neuman and Nelson, 1965). It is difficult to determine the thickness and stratigraphic interval of the Jonesboro Limestone in the windows. Neuman and Nelson (1965) reported an apparent thickness of 2000 feet (610 meters) in the Tuckaleechee Cove window where the best exposure exists, but stated that there is probably considerably less due to tectonic repetition. They also stated that more than half of the 2000 feet (610 meters) of Jonesboro Limestone exposed at the Jockey Creek section is older than the strata exposed in the windows.

Rocks assigned to the Jonesboro Limestone in the Calderwood window are medium- to dark-gray, fine-grained, medium- to thick-bedded limestone. Some beds contain wavy, silty laminations and clay partings. Calcite-filled fractures are common. These lithologies are consistent with those from the lower part of the Jonesboro Limestone in the Valley and Ridge and also are much like lithologies that occur in the Stonehenge Limestone of the central Appalachians.

Few macrofossils have aided in the determination of the age of the rocks in the Calderwood window. Neuman and Nelson (1965) reported an unidentifiable species of the brachiopod *Finkelnburgia* from near the western edge of the window, and thus concluded that these rocks belong to the lower part of the Jonesboro Limestone and are equivalent to the Longview Dolomite and Kingsport Formation of the Valley and Ridge province. This correlation was consistent with their report of Longview Dolomite equivalents from the Cades Cove window.

CONODONT BIOSTRATIGRAPHY

Four conodont zones or faunal intervals have been erected for the uppermost Cambrian and lowest Ordovician rocks of the North American Midcontinent Province. The Cambrian-Ordovician boundary is currently placed at the base of the *Missisquoia* Zone of trilobite zonation; this equates to a level within the *Hirsutodontus hirsutus* Subzone of the *Cordylodus proavus* Zone of the conodont zonation (Fig. 3). The International Working Group on the Cambrian-Ordovician boundary, part of the International Subcommission on Stratigraphy, International Union of Geological Sciences, is in the process of selecting an international boundary stratotype. One of the possible horizons is the base of the *Cordylodus proavus* Zone that is only slightly lower than the horizon currently used in North American platform sequences. At this time, the base of the *Cordylodus proavus*

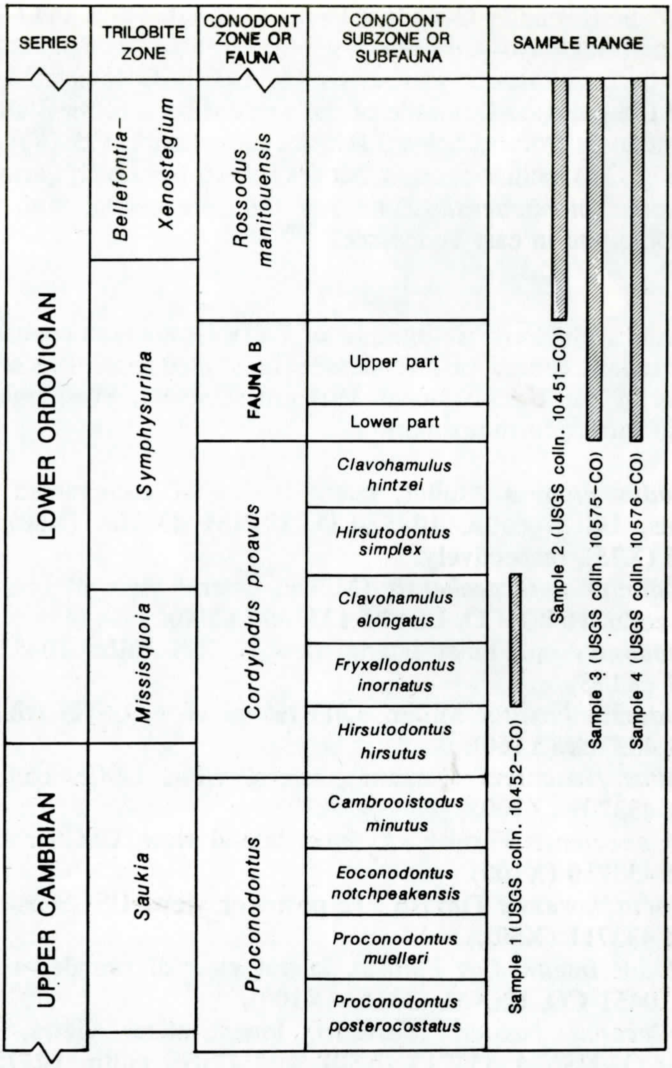

Figure 3. Conodont zones and faunal intervals for the uppermost Cambrian and lowest Ordovician of North America shelf and carbonate platform facies (modified from Miller and others, 1982).

Zone serves as an approximation for the base of the Ordovician in platformal sequences in North America.

Conodonts were recovered from samples collected at four localities in the Calderwood window (Fig. 1). These samples yielded species of conodonts that allow for assignment to a zone or faunal interval (Fig 4, Table 1). Sample 1 (USGS collection 10452-CO) contained conodonts indicative of the *Cordylodus proavus* Zone that straddles the Cambrian-Ordovician boundary of current usage. The specimen of *Fryxellodontus* sp. restricts this sample to the *Fryxellodontus inornatus* or *Clavohamulus elongatus* Subzones, the known range of the genus.

Sample 2 (USGS collection 10451-CO) yielded conodonts of the *Rossodus* *manitouensis* Zone (formerly Conodont Fauna C of Ethington and Clark, 1971) as indicated by the presence of *Loxodus bransoni* Furnish. Assignment of sample 2 to this zone indicates a late-early to early-middle Early Ordovician age, equivalent to most of the Chepultepec Dolomite of the western belts of the Valley and Ridge province. Conodonts from samples 3 (USGS collection 10575-CO) and 4 (USGS collection 10576-CO) include species that are known from both Conodont Fauna B and the *Rossodus manitouensis* Zone and thus are coeval with much of the Chepultepec Dolomite in east Tennessee.

Figure 4. Scanning electron micrographs of Early Ordovician conodonts from the Calderwood window, central-east Tennessee (illustrated specimens are reposited in the collections of the U.S. National Museum (USNM), Washington, D.C.; s.f. indicates sensu formo, form taxonomy).

A, B. *Cordylodus proavus* Müller, lateral views of compressed and rounded elements, USGS colln. 10452-CO, USNM 433704 (X50), and USNM 433705 (X75), respectively.

C. *Eoconodontus notchpeakensis* (Miller), lateral view of rounded element, USGS colln. 10452-CO, USNM 433706 (X100).

D. *Fryxellodontus* sp., inner lateral view, USGS colln. 10452-CO, USNM 433707 (X175).

E. *Hirsutodontus hirsutus* Miller, outer lateral view, USGS colln. 10452-CO, USNM 433708 (X160).

F. *Teridontus nakamurai* (Nogami), lateral view, USGS colln. 10452-CO, USNM 433709 (X100).

G. *Acodus oneotensis* Furnish s.f., inner lateral view, USGS colln 10451-CO, USNM 433710 (X100).

H. *Acontiodus iowensis* Furnish s.f., posterior view, USGS colln. 10451-CO, USNM 433711 (X50).

I. *Cordylodus intermedius* Furnish, lateral view of rounded element, USGS colln. 10451-CO, USNM 433712 (X100).

J, M. *Variabiloconus bassleri* (Furnish), inner lateral views, USGS colln. 10451-CO, USNM 433713 (X50), and USGS colln. 10575-CO, USNM 433716 (X75), respectively.

K. *Loxodus bransoni* Furnish, lateral view, USGS colln. 10451-CO, USNM 433714 (X50).

L. "*Oistodus*" *triangularis* Furnish s.f., outer lateral view, USGS colln. 10575-CO, USNM 433715 (X50).

N. "*Acanthodus*" *lineatus* Furnish, lateral view, USGS colln. 10576-CO, USNM 433717 (X75).

O, P. *Rossodus* sp., inner lateral and oblique posterior views, USGS colln. 10576-CO, USNM 433718 (X60 and X75, respectively).

Q. *Scolopodus sulcatus* Furnish s.f., inner lateral view, USGS colln. 10576-CO, USNM 433719 (X50).

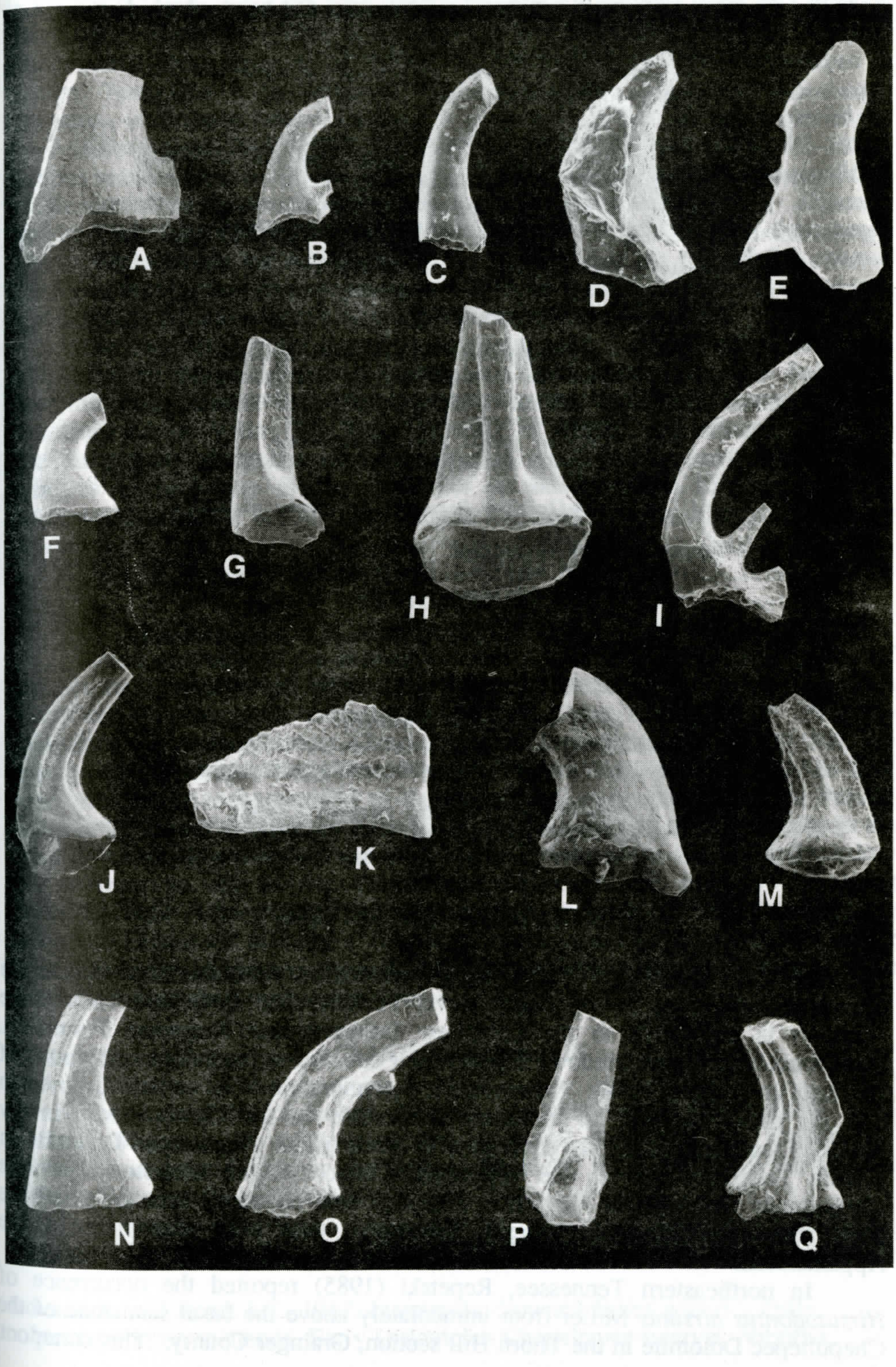
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Table 1. Conodont distribution in samples from the Calderwood window

Sample 1 (USGS collection 10452-CO)
latitude 35° 30.6' N., longitude 83° 59.4' W.
Cordylodus proavus Zone

4 *Cordylodus proavus* Müller elements
3 *Eoconodontus notchpeakensis* (Miller) elements
1 *Fryxellodontus* sp. element
1 *Hirsutodontus hirsutus* Miller element
34 *Teridontus nakamurai* (Nogami) elements

Sample 2 (USGS collection 10451-CO)
latitude 35° 30.6' N., longitude 83° 59.4' W.
Rossodus manitouensis Zone

1 *Acodus oneotensis* Furnish s.f. element
3 *Acontiodus iowensis* Furnish s.f. elements
1 *Cordylodus intermedius* Furnish element
1 *Loxodus bransoni* Furnish element
3 *"Oistodus" mehli* Furnish elements
1 *Scolopodus sulcatus* Furnish s.f. element
2 *Teridontus* sp. elements
6 *Variabiloconus bassleri* (Furnish) elements

Sample 3 (USGS collection 10575-CO)
latitude 35° 30.4' N., longitude 83° 59.6' W.
Conodont Fauna B - *Rossodus manitouensis* Zone

2 *"Oistodus" triangularis* Furnish s.f. elements
1 *Scolopodus sulcatus* Furnish s.f. element
1 *Variabiloconus bassleri* (Furnish) element

Sample 4 (USGS collection 10576-CO)
latitude 35° 30.7' N., longitude 83° 59.9' W.
Conodont Fauna B - *Rossodus manitouensis* Zone

1 *"Acanthodus" lineatus* Furnish element
1 Rossodus sp. element
3 *Scolopodus sulcatus* Furnish s.f. elements

STRATIGRAPHIC SETTING

Neuman and Nelson (1965), using macrofossils, were able to show that the Jonesboro Limestone in the Cades Cove, Tuckaleechee Cove and Wear Cove windows is equivalent to the Longview Dolomite and Kingsport Formation. Conodonts from those windows support their conclusion (conodont collections of Orndorff and others, 1988). However, the determination of an earliest Ordovician age for rocks mapped as Jonesboro Limestone in the Calderwood window indicates that these rocks are equivalent to much of the Chepultepec Dolomite in eastern Tennessee and to the uppermost Conococheague Limestone and the Chepultepec Dolomite in Virginia. Although few conodont data are available from these formations in eastern Tennessee, data exist elsewhere in the Appalachians.

In northeastern Tennessee, Repetski (1985) reported the occurrence of *Hirsutodontus hirsutus* Miller from immediately above the basal sandstone of the Chepultepec Dolomite in the Thorn Hill section, Grainger County. This conodont is known to range from the base of the *Cordylodus proavus* Zone to Conodont Fauna B. Repetski (1985) also showed that conodonts of the *Rossodus manitouensis* Zone range in to, but not through, the uppermost Chepultepec in eastern Tennessee. In Virginia, the Chepultepec interval or Stonehenge Limestone is of Early Ordovician age, ranging from at least the upper part of the *Cordylodus proavus* Zone into the *Rossodus manitouensis* Zone (Orndorff, 1988). Various sections from northeastern Tennessee to northern Virginia can be correlated in this interval of lowermost Ordovician rocks (Bova and Read, 1987). Although the age of the Conococheague-Chepultepec or Conococheague-Stonehenge contact varies within the Appalachians, the lower part of the *Cordylodus proavus* Zone generally occurs in the uppermost Conococheague Limestone in the central Appalachians (Orndorff, 1988, and unpublished USGS collections).

The conodont identified as *Fryxellodontus* sp. in Sample 1 may restrict this sample to the *Fryxellodontus inornatus* or *Clavohamulus elongatus* Subzones. Therefore, this sample may be equivalent to the uppermost Conococheague Limestone of the Valley and Ridge province in western and northern Virginia. The assignment of the remaining samples to the *Rossodus manitouensis* Zone indicates a correlation of the remainder of the Jonesboro Limestone in the Calderwood window to the Chepultepec Dolomite of the Valley and Ridge province.

CONCLUSIONS

Carbonate rocks of the Jonesboro Limestone in the Calderwood window of central-east Tennessee can be assigned to the lower Lower Ordovician based on conodonts. These rocks exposed through the Great Smoky thrust sheet are equivalent to the uppermost Conococheague Limestone through all but the uppermost Chepultepec Dolomite of the Valley and Ridge province. It has long been known that rocks mapped as the Jonesboro Limestone east of the Pulaski fault are the Lower Ordovician equivalents of limestone and dolostone units to the west. With the determination that the carbonate rocks of the Calderwood window are at least as old as the Chepultepec Dolomite and possibly the upper Conococheague Limestone, then the thick succession of rock mapped as Jonesboro Limestone of eastern Tennessee is equivalent to rocks from the upper Conococheague Limestone through the Mascot Dolomite and therefore range through most of the Lower Ordovician.

ACKNOWLEDGMENTS

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RECLAMATION CHARACTERISTICS OF COAL-BEARING ROCKS ON FEDERAL LANDS IN NORTHERN ALABAMA

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ABSTRACT

In order to determine the reclamation characteristics of coal seam overburden in northern Alabama, a study was conducted to determine the kinds of rock occurring in the area and their suitability for surface mine dressing. The core sampling and classification technique devised for this program resulted in 37 types of rock which could be grouped by properties of grain size, composition, color and sedimentary structure. These types were analyzed using standard greenhouse and geochemical techniques. Two rock properties were particularly significant in controlling plant growth. Rocks with finer grain size and those with ancient root penetration structure were best suited for growing fescue. The high pH of all rocks suggests that acid mine drainage should not be anticipated. Long-term field trials and further geochemical testing should be conducted in order to verify these results and to examine the role of trace elements in plant growth.

INTRODUCTION

In many areas that are surface mined for coal or lignite in the United States, the pre-mine topsoils are too thin or otherwise unsuitable for use as surface dressing material on reclaimed spoils (Mott and Zuberer, 1987, Alderdice and others, 1981). In these circumstances a portion of the removed overburden rock may be used as an alternative material for revegetating the site. Such is the case in the western part of the Carboniferous-age Warrior coalfield in northern Alabama, particularly in areas with coastal plain cover, where much of the existing soil material is relatively acidic and potentially toxic to many species used for reclamation. In part of this area (Figure 1), the federal government retains mineral rights to substantial tracts of surface-minable coal. In the early 1980's, a program of leasing these properties led the U.S. Bureau of Land Management to investigate the reclamation characteristics of overburden materials which could potentially be used as post mining surface dressing. The objectives of this program were the determination and characterization of the kinds of rock that overlie the coal beds with the intent to identify those that would be most (or least) suitable for revegetation. A full report on this study is given elsewhere (Ferm and Weisenfluh, 1981a) but a summary of the significant results is presented here.

Information concerning rocks that may (or may not) be suitable for revegetation of surface mined lands is not complete. Anecdotal information about this problem is abundant and there are some very good data based on rigorous testing. For example, black shales in eastern Kentucky and in western Pennsylvania (Caruccio and others, 1981) are believed to have a potential for toxicity due to the presence of framboidal pyrite that, upon oxidation yields acidic ground water. Sandstones, because they are resistant to physical breakup, do not readily produce soil and create obstacles on a reclaimed surface. Also, while specific chemical attributes related to toxicity, like sodium content, have been studied extensively there is little information guiding recognition of rocks that contain excessive quantities of such elements short of complex elemental analysis.

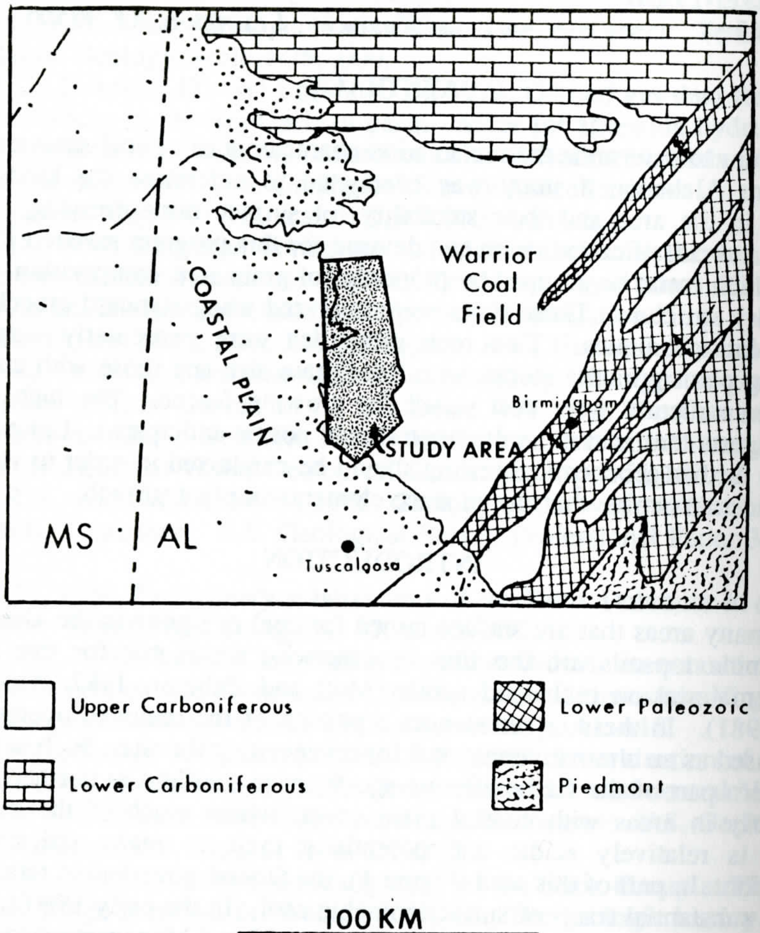

Figure 1. Location of the Warrior coal field and study area containing federal lands.

The central problem appears to be the lack of a widely used classification system of the rocks that would allow precise and repeatable identifications and relating these identifications with potential for plant growth. Consequently, test results are generalized or averaged over vaguely defined rock types. As previously noted "black shales" are generally regarded as being potentially toxic but it is not known whether "dark gray" shales are more or less so. Rock types could be tested in a number of ways to determine their suitability for reclamation if a precise and repeatable system of classification were developed. This concept comprised the basis for the experimental plan used in this study. A collection of rock types was made from rock core such as would be obtained during pre-mine drilling and a system of classification was devised so that different kinds of rocks could be identified under field conditions. Next, samples of each type were tested for reclamation potential by standard greenhouse experiments to determine plant growth capability and by geochemical analysis to identify potentially toxic or beneficial elements. Finally both greenhouse and geochemical data were compared to rock types to evaluate their reclamation potential.

MATERIALS AND METHODS

Sample Collection and Development of the Rock Classification

Twenty continuous cores were obtained from locations that represented the geographic and stratigraphic range of coal-bearing rocks of the area. Each core was examined and marked at every place where one rock type was in contact with another. Each marked core was then sampled by removing a piece roughly 15 centimeters in length at random locations between each marked segment unit on the core (Figure 2). This procedure yielded a collection of pieces that represented recognizably different kinds of rocks in proportion to their occurrence in the cores. The classification was developed by hand sorting the individual pieces into groups that had similar grain size, color or other properties that could be described under field conditions. The degree to which these groups could be repeatedly identified was determined by combining samples of two or more groups and requesting a number of observers to reproduce the initial groups using the same criteria by which they were defined. If the collective results of these second groupings differed no more than 5% of the samples, the group of samples was considered to represent a type that could be repeatably recognized.

Samples of core 1.2 meters in length representing each rock type defined by methods described above were collected for greenhouse and geochemical analyses performed at the U. S. Forest Service Laboratory at Berea, Kentucky.

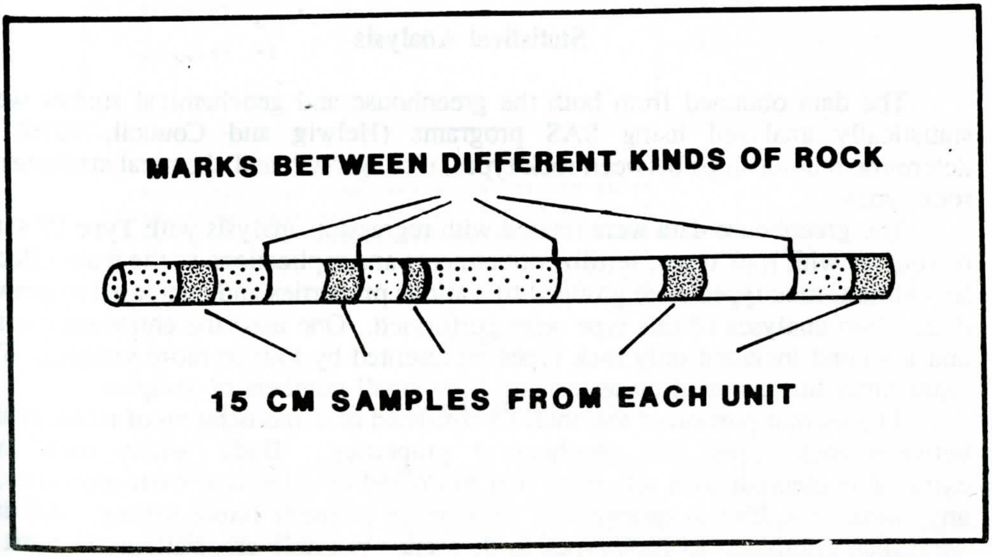

Figure 2. System for sampling rock core.

Greenhouse Experiments

The greenhouse experiments were designed to test the ability of each rock type to grow plants and to respond to different kinds of fertilizer treatment. Each sample was ground to pass 100 mesh and was sowed in coffee cup-size containers with "KY 31" fescue, a common "cover" plant of the region. Four treatments included no fertilizer (control), nitrogen (50 ppm ammonium nitrate in solution), nitrogen and phosphorous (43 ppm monobasic calcium phosphate in suspension) and nitrogen, phosphorous and potassium (42 ppm potassium chloride in solution). Each treatment was replicated three times yielding a total of 12 pots per sample. The plant material was hand harvested after about 60 days, dried and weighed as a measure of growth potential.

Geochemistry

To further characterize the rock types and test for nutrient (or toxicity) potential among them, a series of chemical tests was performed on the minus 100 mesh material. The first group of tests included what can be called "whole rock" properties. These are pH, conductivity, phosphorous by both Bray and Olson methods, total carbon and total sulfur. Acidity and extractable aluminum were measured for a few selected rock types on the basis of the pH results.

A second group of tests included elemental concentrations of weak acid (50:50 .05N HCL and .025N H_2SO_4) leacheates. These were determined by plasma emission and atomic absorption spectrometry (Oborne and West, 1972). The double acid extraction procedure, described by Perkins (1970), is designed to estimate the amounts of certain elements in soil material which would be available as plant nutrients (or contaminants). The elements in this set of tests included Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ge, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Sn, Sr, Ti and Zn.

Statistical Analysis

The data obtained from both the greenhouse and geochemical studies were statistically analyzed using SAS programs (Helwig and Council, 1979) to determine relationships between rock types, plant growth and chemical attributes of rock types.

The greenhouse data were treated with regression analysis with Type IV sums of squares with rock types, fertilizer treatments and replications as the main effects. In addition, rock types were grouped by various properties and compared to growth data. Two analyses of this type were performed. One used the entire sample set and a second included only rock types represented by four or more samples. The latter procedure avoided biases arising from small numbers of samples.

The second portion of the analysis consisted of demonstration of relationships between rock types and geochemical properties. Both "whole rock" and extractable element data sets were first examined to determine what properties, if any, were of sufficient quantitative importance to merit future testing. All data were then compared to rock types to determine possible associations. In most of these analyses direct measurement values were used but the very large number of variables generated by the extractable element data required an initial step of data reduction. The procedure used was R-mode factor analysis with varimax rotation. This method groups into "factors" those elements that display similar patterns of variation. Finally the geochemical data and "factors" were compared to rocks having those particular properties that were associated with variation in plant growth. All of these comparisons utilized a ranking method and simple one way analysis of variance.

Table 1. Properties and subtypes used in classification with corresponding numeric codes. "x" in numeric code indicates a variable digit.

GRAINSIZE		COMPOSITION OF PEBBLES AND SAND		SEDIMENTARY STRUCTURE	
PEBBLY SANDSTONE	7xx	COAL PEBBLES	7x8 7x9		
SANDSTONE	5xx	QUARTZ POOR SAND	x4x	CROSS BEDDED	xx1
		QUARTZ RICH SAND	x6x	LAYERED	xx2
		COLOR		STREAKED	xx3
SANDY SHALE AND SANDY FIRECLAY *1 (SILTSTONE)	3xx			MASSIVE	xx4
				PARTLY CHURNED	xx5
		LIGHT GRAY	x3x *3	CHURNED	xx6
		DARK GRAY	x2x *4	FIRECLAY (ROOT PEN- ETRATED)	xx7
		BLACK	x1x *5		
SHALE AND FIRECLAY *2	1xx			BURROWED	xx8
				FOSSIL SHELLS	xx9

*1 Finer than sandstone but gritty to touch
*2 Finer than sandstone but smooth to touch
*3 N 7-8, Geological Society of America color chart, 1963
*4 N 4-6, Geological Society of America color chart, 1963
*5 N 1-3, Geological Society of America color chart, 1963

RESULTS

Rock Classification

Hand sorting of the 803 specimens from the 20 rock cores yielded a total of 37 rock types that could be consistently recognized. The properties by which these types could be identified were grain size, composition of sand and pebbles in sandstones and pebbly sandstones, color in finer grained rocks and sedimentary structure in rocks of all grain sizes except pebbly sandstone. In these rocks the large particle size precluded identification of structural features. Recognition of all classes was by visual inspection except the differentiation of sandy shale/sandy fireclay and shale/fireclay grain sizes which relied on tactile testing for grittiness. As a last step, the name of the rock was rendered in the form of a numeric code which aided in data manipulation and had the potential of speeding data recording. Table 1 lists the rock properties and their corresponding code designations. A full description of the classification accompanied by color photographs of each rock type is given by Ferm and Weisenfluh (1981b). A list of all rock types encountered in the 20 cores, their frequency of occurrence expressed as a proportion and the number of samples submitted for greenhouse and geochemical analysis are given on Table 2.

Table 2. List of rock types with their corresponding codes, frequency of occurrence in cores and number of samples for analytical work.

ROCK NAME	CODE	FREQ %	SAMP
PEBBLY SANDSTONES AND CONGLOMERATES		5.3	4
GRAY SHALE AND/OR IRONSTONE PEBBLE CONGLOMERATE	741	1.6	0
GRAY SHALE PEBBLE CONGLOMERATE	742	1.0	0
GRAY SANDSTONE WITH COAL BANDS	748	1.0	0
GRAY SANDSTONE WITH COAL SPARS	749	1.6	3
HARD SANDSTONE WITH COAL BANDS	768	0.1	1
SANDSTONES		30.3	85
GRAY MASSIVE SANDSTONE	544	4.8	19
CARBONATE CEMENTED SANDSTONE	644	2.0	0
GRAY CROSSBEDDED DANDSTONE	541	5.0	22
GRAY SANDSTONE WITH SHALE STREAKS, RIPPLED	543 RIP	5.5	17
GRAY SANDSTONE WITH SHALE STREAKS, FLAT	543 FLT	4.0	10
GRAY ROOTED SANDSTONE	547	2.0	2
GRAY BURROWED SANDSTONE	548	0.5	2
HARD MASSIVE SANDSTONE	564	0.8	2
HARD CROSSBEDDED SANDSTONE	561	1.8	5
HARD SANDSTONE WITH SHALE STREAKS	563	0.4	1
GRAY CHURNED SANDSTONE	546	0.1	2
SANDSTONE MUDFLOW	019	3.3	3
GRAY SANDSTONE WITH FOSSIL SHELLS	549	0.1	0
SANDY SHALES (SILTSTONES) AND SANDY FIRECLAYS		46.4	129
DARK GRAY SHALE AND INTERBEDDED SANDSTONE, RIPPLED	322 RIP	9.2	27
DARK GRAY SHALE AND INTERBEDDED SANDSTONE, FLAT	322 FLT	7.2	23
DARK GRAY SHALE WITH SANDSTONE STREAKS	323	8.5	31
LIGHT GRAY GREEN SHALE WITH SANDSTONE STREAKS	333	2.5	9
DARK GRAY MASSIVE SANDY SHALE	324	2.9	8
DARK GRAY MASSIVE CHURNED SANDY SHALE	325	8.5	21
DARK GRAY SANDY FIRECLAY	327	1.1	2
LIGHT GRAY GREEN SANDY FIRECLAY	337	1.0	1
DARK GRAY BURROWED SANDY SHALE	328	2.9	12
SANDY SHALE MUDFLOW	018	2.5	1
DARK GRAY SANDY SHALE WITH FOSSIL SHELLS	329	0.1	0
SHALES AND FIRECLAYS		16.2	42
BLACK SHALE	114	2.7	6
BLACK SHALE WITH COAL STREAKS	113	1.0	0
DARK GRAY SHALE WITH COAL STREAKS	123	0.5	1
DARK GRAY SHALE	124	6.3	21
LIGHT GRAY GREEN SHALE	134	2.5	8
DARK GRAY FIRECLAY	127	2.0	4
LIGHT GRAY GREEN FIRECLAY	137	1.1	1
DARK GRAY SHALE WITH FOSSIL SHELLS	129	0.1	1

Greenhouse Results

The results of regression analysis on greenhouse data with main effects of fescue growth, fertilizer treatment and rock type are shown at "A" on Table 3. All effects are shown to be significant and, as expected, fertilizer treatment has the greatest effect on plant growth. Statistics for the full data set and that composed of types with four or more samples show comparable results with slight improvement for the limited set. Figure 3 shows that, among treatments, addition of nitrogen alone yields slight improvement that is greatly enhanced by the addition of phosphorous. Further addition of potassium appeared to have a slightly negative overall effect.

While effects of all rock types are relatively small, grouping of rocks by specific rock properties yields improved results as shown on "B", "C" and "D" on Table 3 and Figure 3. First, sandstones and pebbly sandstones (codes 5xx, 7xx, and 019 on Figure 3) have significantly lower yields irrespective of treatment than do the finer grained rocks and these coarser grained rocks are the only ones that respond positively to potash treatment. This is not an unexpected result as the coarse-grained rocks are rich in the mineral quartz which is nutritionally inert whereas the finer grained rocks contain more fine-grained micas and clays which include potassium within their structure.

Table 3. Results of multiple regression analysis for fescue data. Reported F statistics are all significant at the .01% level. Results given for analysis using all rock types and those represented by 4 or more samples.

VARIABLE	ALL TYPES	TYPES W/ 4 OR MORE SAMP.	VARIABLE LEVELS
A MAIN EFFECTS			
1 TREATMENTS	3261.21	12378.67	4
2 REPLICATIONS	115.81	111.36	3
3 ROCK TYPES	29.80	32.88	35 AND 18
4 ROCK TYPE X TREATMENT	4.38	5.37	
B ROCK TYPES GROUPED BY GRAIN SIZE			
1 TREATMENTS	9011.76	9132.36	4
2 REPLICATIONS	100.13	101.13	3
3 BETWEEN GRAIN SIZE GROUPS	182.76	155.76	3
4 WITHIN SANDSTONES (5XX)	23.82	23.78	9 AND 5
5 WITHIN SILTSTONES (3XX)	5.02	6.11	8 AND 7
6 WITHIN SHALES (1XX)	13.28	17.97	7 AND 4
C ROOT PENETRATED ROCKS VS. OTHERS			
1 TREATMENTS	1915.19	1714.25	4
2 REPLICATIONS	91.67	95.16	3
3 ROCK GROUPS	99.91	131.63	2
4 ROCK GROUP X TREATMENT	16.65	23.68	
D SHALES GROUPED BY COLOR			
1 TREATMENTS	1259.55	1135.93	4
2 REPLICATIONS	25.92	24.40	3
3 COLOR GROUPS	10.91	11.90	3
4 COLOR GROUPS X TREATMENT	NOT SIGNIFICANT		

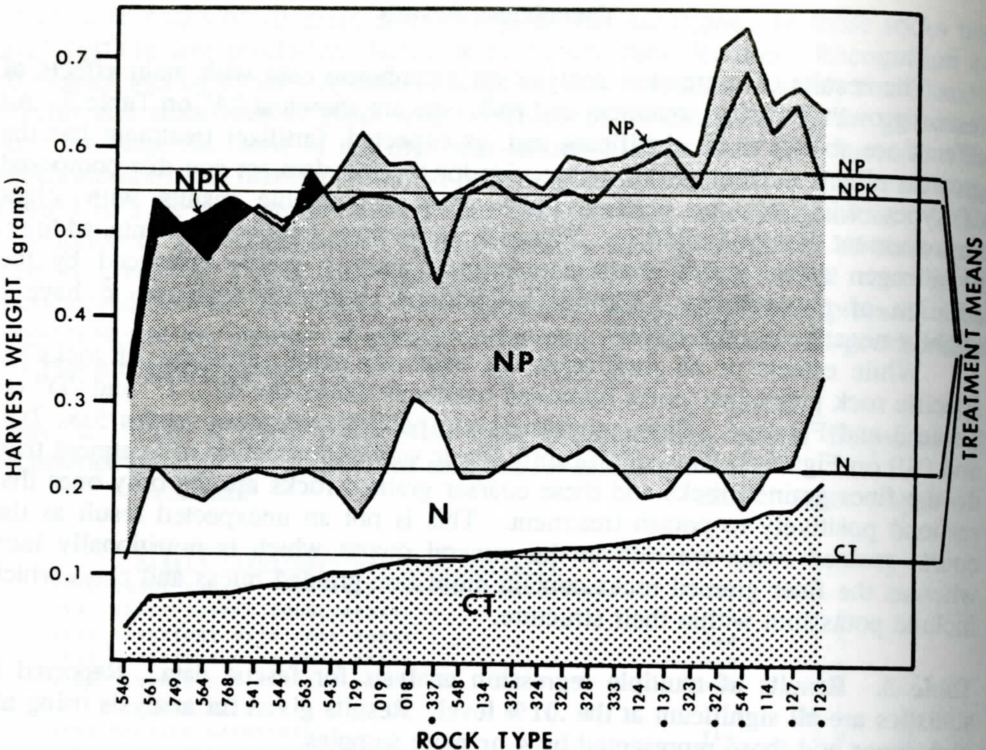

Figure 3. Results of fescue growth versus rock type (given by numeric code) ranked by control means. For English equivalents to rock codes see Table 1. * = rocks with fireclay texture.

The second noticeable effect of rock properties is that, among the rocks which produce the highest yields, most display a "fireclay" or ancient root-penetration structure ("C" on Table 3 and coded xx7 and 123 on Figure 3). Moreover, these types respond especially well to the nitrogen/phosphorous treatment. Fireclays, also called seatearth or underclay, are believed to represent fossil soils and, therefore, can be expected to be somewhat depleted in mineral nutrients. That they retain existing soil texture and structure may make them better able to make available nutrients to plants.

Data at "D" on Table 3 shows that color was only a minor factor in affecting plant growth. However, black shales (114 on Figure 3) which in other areas are reported to be a source of toxicity detrimental to plant growth, here are among the high yield rock types.

Geochemical Results - General Characteristics

Summary data for "whole rock" analyses are given in Table 4. The most conspicuous attribute of these rocks is their uniformly high pH values. This is reinforced by generally low total sulfur and exchangeable acidity levels among samples where this property was measured. The maximum acidity values in each of these cases arise from one or two samples taken near the top of the cores where they are proximal to the lower part of the soil zone, which, in the region, is reported to be acidic. Unweathered rocks are uniformly neutral or slightly alkaline. Other properties on Table 4 display a similar pattern of uniformity with the few exceptionally high values arising from one or two samples, eg., 11.49% carbon represents a sample with visible layers of coal.

Table 4. Average values and ranges of "whole rock" data for 260 samples.

VARIABLE	UNIT OF MEASURE	MEAN	MINIMUM VALUE	MAXIMUM VALUE
pH	-	8.48	1.15	9.95
CONDUCTIVITY	millimohs/cm	0.27	0.01	5.15
BRAY PHOSPHORUS	ppm	1.49	0.04	5.15
OLSON PHOSPHORUS	ppm	0.98	0.00	8.12
ACIDITY	milliequivalents/100g	0.11	0.00	8.00
EXTRACTABLE ALUMINUM	milliequivalents/100g	0.008	0.00	1.55
TOTAL CARBON	%	1.11	0.04	11.49
TOTAL SULFUR	%	0.14	0.00	1.39

Ranges in concentrations of acid extractable elements are shown on Figure 4, where elements are ranked by their mean concentration. Proportional distribution of the elements are not known, but Despard (1980) reports from similar rocks in the area that the first six elements on this diagram (Ca, Fe, Al, Mg, Si and K) make up approximately 95 to 98 percent of the rock. It may be assumed that the remaining elements can comprise only a fractional percentage.

Figure 4 also compares concentrations in leachates with average whole rock concentrations in sedimentary rocks as given by Turekian and Wedepohl (1961). Most elements show concentrations far less than are found in sedimentary whole rock analyses with extraction percents ranging from 0.1 to 50. A smaller group of trace elements that includes As, Bi, Sn, Se and Cd were found in concentrations far exceeding the sedimentary rock averages (150 to 2900%). This may reflect greater initial amounts of these elements or a higher degree of solubility (in an acidic medium) of compounds that include these elements (Aubert and Pinta, 1977). Whatever the case, the concentrations, while high, are within the normal ranges for soils in the Soviet Union reported by Vinogradov (1959).

Geochemical Results - Comparison to Rock Types

The greenhouse experiments showed that two attributes of rock types, grain size and sedimentary structure, were associated with fescue growth. Coarse grained rocks - sandstones and pebbly sandstones - had less growth potential than finer grained rocks, and rocks with a "fireclay" or ancient soil structure had a greater potential than rocks having other kinds of sedimentary structure. These two attributes were compared to the "whole rock" and extractable element data to determine possible associations between them that could be related to plant growth.

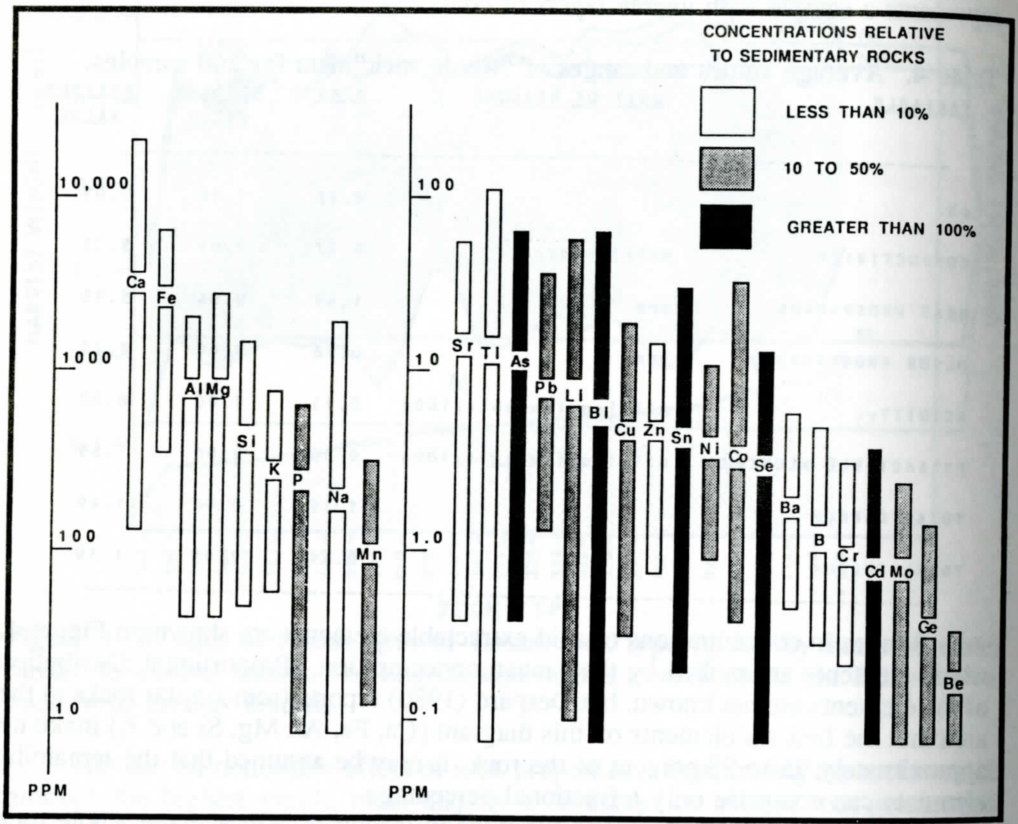

Figure 4. Mean values and ranges for extractable elements. Data given in ppm and ranked by means on logrithmic scale. Extractable concentrations were compared to average sedimentary whole rock concentrations given by Turekian and Wedepohl (1961) and grouped by the resulting estimate of percent extracted.

Because of the high degree of uniformity of "whole rock" data, there were only slight relationships to rock types. Most measurements - pH, phosphorous, acidity and extractable aluminum - showed no relation to differences in grain size or to "fireclay" versus other structures. Higher conductivity, sulfur and carbon content, were weakly associated with shale/fireclays and sandy shale/sandy fireclays, but these results were not unexpected. Clay minerals which are major components of finer grained rock would be expected to produce higher conductivity and most fine-grained rocks are darker and tend to contain more carbonaceous matter than coarser ones. Also, most visible sulfur in the form of pyrite is found in dark-colored shales.

Before the extractable element data were compared to rock types, they were reduced into "factors" made up of mutually varying elements. The results of this analysis are shown on Table 5. The nine "factors" shown here accounted for 75 percent of the total variance in the extraction data, and factors one through four accounted for 80 percent of that amount. Elements associated with each factor were determined by loading scores for the varimax rotated factors. Elements of factor one are clearly associated with minerals in the clay-mica-feldspar group. Elements of factors two, five and six are normally attributed to sulfide minerals, however the high concentrations (i.e. ease of extraction) of Bi, As, Cd, Se and Sn suggest a partial contribution by organic constituents. Factors three and four contain elements derived from carbonate minerals and possibly, in the case of Ti (F4), heavy minerals. Factor eight (Fe, Mn) is interpreted to be a siderite association while factors seven and nine show no clear mineral affinities.

Table 5. Results of R-Mode factor analysis. Associated elements derived from factor loading scores after varimax rotation and listed in order of weighting. Interp indicates probable mineral associations. Also given are elemental means in ppm for rocks grouped by specific rock properties. Numbers in parens denote anomalous values (generally low).

FACTOR-INTERP #	ELEMENT	SANDSTONE MEAN	SANDY SHALE MEAN	SHALE MEAN	FIRECLAY MEAN
F1 - CLAY/MICA	AL	409.00	628.00	644.00	(382.00)
	Si	249.00	401.00	465.00	371.00
	K	129.00	258.00	287.00	230.00
	Fe	1382.00	2505.00	2426.00	(1338.00)
	B	0.70	1.42	1.72	1.34
	Mg	326.00	666.00	566.00	(265.00)
	P	158.00	257.00	283.00	(73.00)
	Zn	3.74	4.94	7.18	4.85
	Mn	77.00	121.00	102.00	(40.00)
F2 - SULFOPHILE ORGANIC	Be	0.14	0.23	0.24	0.19
	Ge	0.36	0.39	0.38	(0.22)
	Se	3.19	3.30	3.11	(1.60)
	Bi	(7.41)	5.92	7.44	5.30
	Ni	3.07	4.50	4.78	4.06
F3 - CARBONATE	Li	(9.38)	7.76	7.60	(3.20)
	Sr	12.30	15.20	17.60	15.40
	Ca	(3035.00)	2548.00	235.00	(775.00)
	Ba	(1.82)	1.78	1.89	(1.28)
	Mo	0.72	0.97	0.95	(0.45)
F4 - HEAVY MINERAL CARBONATE	Ti	10.80	17.70	14.70	(9.10)
	Pb	8.40	9.12	9.44	(4.45)
F5 - SULFOPHILE ORGANIC	Cd	0.84	0.92	1.07	(0.72)
	As	11.60	12.50	15.50	(8.20)
F6 - SULFOPHILE ORGANIC	Sn	4.01	5.13	5.26	(2.41)
	Mo	0.72	0.97	0.95	(0.45)
F7 - ?	Na	72.00	188.00	344.00	(454.00)
	Ba	(1.82)	1.78	1.89	(1.28)
F8 - SIDERITE	Mn	77.00	121.00	102.00	(40.00)
	Fe	1382.00	2505.00	2426.00	(1338.00)
F9 - ?	Ba	(1.82)	1.78	1.89	(1.28)

Comparison of these "factors" with rock types (Table 5) yielded results which support the whole rock and greenhouse data . On the basis of grain size alone, the coarser grained rocks - sandstone and pebbly sandstone - were deficient in most elemental groups, lacking clay/mica type minerals as well as carbonates and sulfides. In contrast, most fine-grained rocks were richer in these components. The major exception to this are the rocks with a fireclay or ancient soil structure. These rocks are as deficient in some exchangeable cations as are the sandstones and pebbly sandstones and are markedly depleted relative to all rocks in P, Mn, As, Pb, Li, Sn, Se, Ba, Mo and Ge.

While the ability of a rock to make available plant nutrients is certainly related to its clay content, it is not clear why fine-grained rocks other than those with a "fireclay" structure did not grow fescue as well as those with. They probably have a similar clay mineralogy, but apparently the fireclays give up their nutrients more readily. This phenomenon could arise from the difference in texture of the rocks or possibly because as pre-existing soils the fireclays have rendered what nutrients they have in simpler forms. Alternatively, some of the elements in which the fireclays are deficient fall within the "easily extracted" group (Figure 4) and this may suggest some low level toxicity in other rocks. Consequently, geochemical data were compared directly to the plant growth data to evaluate potential elemental effects.

Geochemical Results - Comparison to Fescue Growth

In this analysis both geochemical data sets (whole rock and factors weighted per sample) were regressed against control fescue weights averaged across replicates. The resulting multiple correlation coefficients (R_2) indicate significant relationships only for total carbon (R_2=.26) and Factor 1, the clay-mica group (R_2=.49). Again, this outcome is entirely consistent with the above findings.

Among the elements in which the high-yield fireclays are deficient, none are negatively correlated with fescue weight at significant levels (Pearsons product-moment test). Hence, these data cannot support the hypothesis of toxicity. If such an effect is present, it is masked by the larger controls of other variables.

SUMMARY AND CONCLUSIONS

The principle objectives of this study were to develop a field oriented megascopic classification of rock types occurring as overburden in the Alabama coal measures and to determine if any of these rock types were particularly well suited for revegetation of surface-mined areas. The results, which are summarized below, are all at the bench level of testing and should be verified by field trials.

The classification process yielded about 37 rock types that could be repeatedly recognized, of which only 24 are frequently occurring. The results of greenhouse and geochemical testing suggests that many fewer categories would provide sufficient data for most reclamation procedures. Among rock types, sandstones and pebbly sandstones, in addition to their non-slaking character, do not respond well to nutrient additions and, where possible, should not be used as a surface dressing. Any fine-grained rock, sandy shale/sandy fireclay or shale/fireclay, would be more suitable. Differences between shales and sandy shales (siltstones) do not warrant segregation of these types.

Among fine-grained rocks, those with a "fireclay" structure would be the most suitable. Their crumbly texture and capacity to make nutrients available make them most suited as a surface dressing. These rocks generally underlie coal seams and, because of this position, they could easily provide a surface covering to spoils after the coal has been removed. The ability of fireclays to sustain plant growth and to respond similarly to other kinds of vegetation must be established by long-term field experiments.

All unweathered rocks proved to be neutral or slightly alkaline and in general low in sulfur. Acid mine drainage, except that which may originate from the coal, is not anticipated. Black shales which elsewhere have been shown to be toxic, can be expected to produce better yields than average. The relatively low concentrations of extractable elements in the high-yield "fireclay" group remains enigmatic. Additional testing should be performed to evaluate the whole rock concentrations of elements, their forms of occurrence and plant uptake behavior.

ACKNOWLEDGMENTS

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STRATIGRAPHIC REVISION AND FACIES ANALYSIS OF THE UPPER CRETACEOUS CUSSETA SAND, COASTAL PLAIN OF ALABAMA

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ABSTRACT

The Cusseta is currently the lower member of the Ripley Formation in Alabama while it holds formational rank in adjacent Georgia. Because the Cusseta is the lateral equivalent of the Demopolis Chalk of Alabama and because the Cusseta-Demopolis package and Ripley are separated by a sharp lithic boundary, the authors herein revise, without redefining or completely redescribing, the Cusseta Sand Member of the Ripley Formation and thereby raise its rank to that of a formation in Alabama.

The Upper Cretaceous Cusseta Sand in Alabama consists of five sedimentary facies: 1) *Ophiomorpha*-bearing, trough and planar cross-stratified sand (barrier-island shoreface and tidal-inlet deposits); 2) interlaminated fine sand and silty clay (back-barrier tidally influenced deposition); 3) bioturbated clayey fine sand (lower-shoreface to inner-shelf deposits); 4) glauconitic siltstone (inner-shelf deposits); and 5) thin hummocky cross-stratified sand beds (tempestite deposition within inner-shelf deposits).

The Cusseta Sand consists of three genetic packages which developed as a result of cyclic sea-level change. That the sea-level cycles are eustatic is shown by biostratigraphic correlation with the global eustatic curve; the Cusseta cycles match very closely with the global sea-level changes.

INTRODUCTION

The Upper Cretaceous Cusseta Sand is exposed in the Gulf Coastal Plain from central Alabama to eastern Georgia. This report describes the Alabama portion of the Cusseta outcrop (Figure 1). The purposes of this paper are first to revise (raise) the formal stratigraphic rank of the Cusseta Sand, currently a member of the Ripley Formation and second to describe, correlate, and analyze the facies stratigraphy and sea-level cyclicity.

At present, in eastern Alabama the Ripley Formation is composed of the Cusseta Sand Member at its base and an unnamed member above. In west-central Alabama the Cusseta Sand Member is not present and the Ripley consists only of the unnamed member (Figure 2; Eargle, 1948, 1950; Copeland, 1968b). Prior to Eargle's (1948, 1950) work, the Cusseta Sand in Alabama held formational status, which it still holds in Georgia (Pickering and others, 1976). In the next section, we recommend that the Cusseta be restored to formational rank in Alabama.

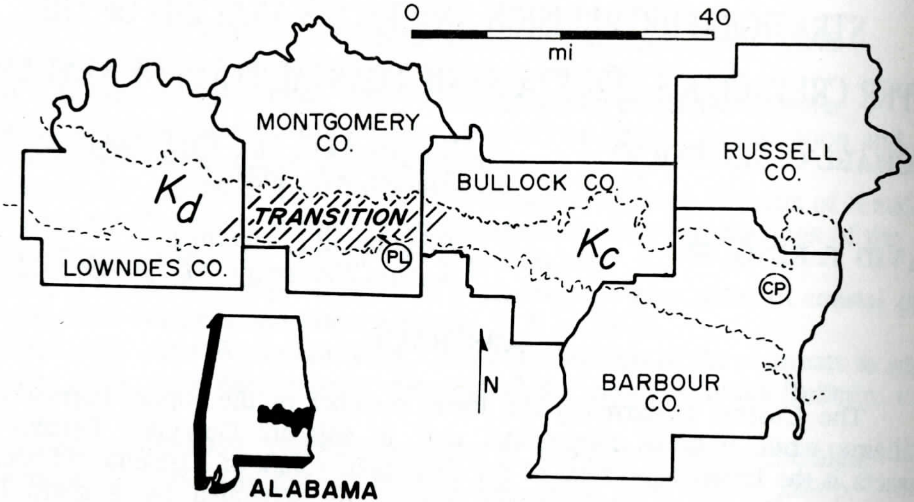

Figure 1. Generalized geologic map showing outcrop belt of Cusseta Sand (Kc) in eastern and central Alabama, the Cusseta-Demopolis transition zone (Montgomery County), and the laterally equivalent Demopolis Chalk (Kd) (after Copeland, 1968b). Study area spans the region from western Montgomery County to north central Barbour County. Key locations mentioned in text: PL = Pine Level, CP = Cowikee Prairie.

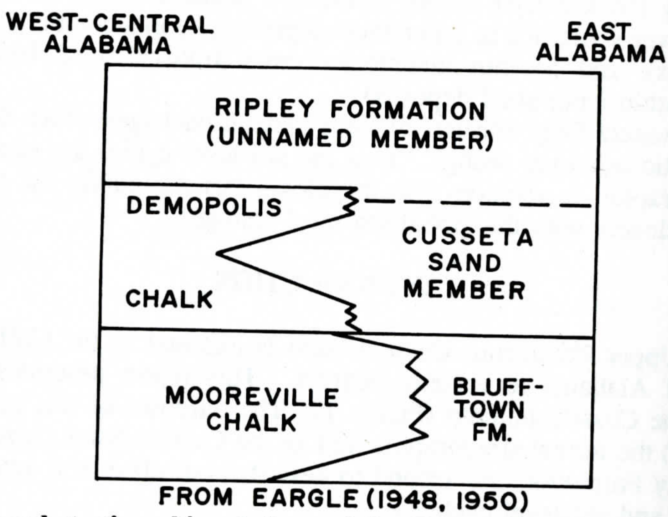

Figure 2. General stratigraphic relations of the Cusseta Sand Member of the Ripley Formation in the study area according to Eargle (1948, 1950).

STRATIGRAPHIC REVISION OF THE CUSSETA

Historical Background

The term Cusseta was first suggested by Veatch (1909, p. 88). He intended that the term be provisionally applied to sands well exposed in the vicinity of

Cusseta, Chattahoochee County, Georgia. These sands were the second of four subdivisions of a Ripley Formation in Georgia comprised of a "Lower (Blufftown) marl," a "Middle (Cusseta) sand (unconsolidated)," an "Upper (Renfroes) marl," and an "Upper sand (Providence) unconsolidated" (Veatch, 1909, p. 86). As a part of a project to revise and redefine the stratigraphic units of the Georgia Coastal Plain, Cooke and Munyan (1938) took Veatch's Ripley Formation and made individual formations of his provisional subdivisions. After their publication, the Blufftown Formation, Cusseta Sand, Ripley Formation, and Providence Sand had equal formational rank. Similar work in Alabama and Mississippi by Stephenson and Monroe (1938), showed that the Cusseta Sand had formational rank in that part of the Coastal Plain. According to the map and correlation presented by Stephenson and Monroe (1938, their figures 1 and 2), the Cusseta Sand is bounded by disconformities and is situated stratigraphically between the Blufftown and Ripley Formations in eastern Alabama. Further, their correlation in central Alabama showed that the Cusseta Sand grades laterally into the "Demopolis member" of the Selma Chalk (now the Demopolis Chalk of the Selma Group). The same stratigraphic relations are expressed in the subsequent, more voluminous and more frequently cited work by Monroe (1941).

Eargle (1948) revised the Cusseta Sand in Alabama calling it the Cusseta Sand Member of the Ripley Formation. This revision was presented because of Eargle's view that the Selma Group and its lateral equivalents, including the Ripley Formation and its Cusseta Sand Member, were developed by fining-upward cyclic deposition. He regarded the Cusseta Sand as the early, coarse-grained depositional phase of a cycle that ended at the top of the Ripley Formation. He recognized no distinct break between the Cusseta and Ripley as did Stephenson and Monroe (1938) and Monroe (1941). Later, Eargle (1950) published a detailed map, correlation among three composite measured sections along north-south highways, and additional text in support of his stratigraphic revisions.

Eargle's view of stratigraphic relations with regard to the Cusseta has been used widely since 1950. Use of Eargle's stratigraphy in post-1950 Geological Survey of Alabama publications (especially LaMoreaux and Toulmin, 1959) and important works by Copeland (1968a, 1968b) and Szabo and others (1988) furthered his analysis as the accepted synthesis of physical stratigraphy for the Cusseta Sand.

Discussion

In the correlation presented by Eargle (1950), two of his composite sections include the Cusseta-Ripley section. These sections were developed by studying outcrops along U.S. Highway 241 (now U.S. 431) in eastern Russell County, Alabama, and U.S. Highway 29 in southern Macon and southern Bullock Counties, Alabama. In the former section, the columnar lithologic description given by Eargle (1950) supports his fining-upward or "cyclic" interpretation of the Cusseta Sand Member and the overlying Ripley Formation because the Cusseta sands are in part coarse-grained and the Ripley section is largely very fine-grained, clayey sands. However, his U.S. 29 section does not support his single-cycle, fining-upward model because his figure shows the Cusseta to be comprised of fine sand at the base, fine- to coarse-grained sand in the middle, and calcareous clay at the top.

This Cusseta section is overlain by medium- to coarse-grained sand at the base of the Ripley while coarse- to fine-grained sand occurs higher in the Ripley. This grain-size arrangement is inconsistent with the genetic relationship of the Cusseta and Ripley envisioned by Eargle (1950).

The difference in interpretation of the Cusseta's physical stratigraphy presented first by Monroe (1941) and later by Eargle (1948, 1950) is striking in scope. In addition to the difference in formal stratigraphic rank they assigned to the Cusseta, Monroe (1941) and Eargle (1950) also mapped the unit quite differently. Monroe (1941) stated that in Montgomery County, Alabama, the Cusseta Sand "is divided into two westward-extending tongues by an eastward-extending tongue" of the Demopolis Chalk. Monroe's map of the Cusseta Sand and Demopolis Chalk in the transition zone (Montgomery County) is shown in Figure 3A. In contrast, the Montgomery County portion of Eargle's (1950) map (Figure 3B) shows only one westward-extending tongue of the Cusseta which is underlain and overlain by tongues of Demopolis Chalk. This disparity is explained by a basic difference in mapping strategy between Monroe and Eargle as applied in the transition zone between the Cusseta and Demopolis. While Monroe's work was largely descriptive, Eargle used a genetic-synthesis approach, or geologic paradigm, based on his concept of fining-upward cyclic deposition (Eargle, 1950).

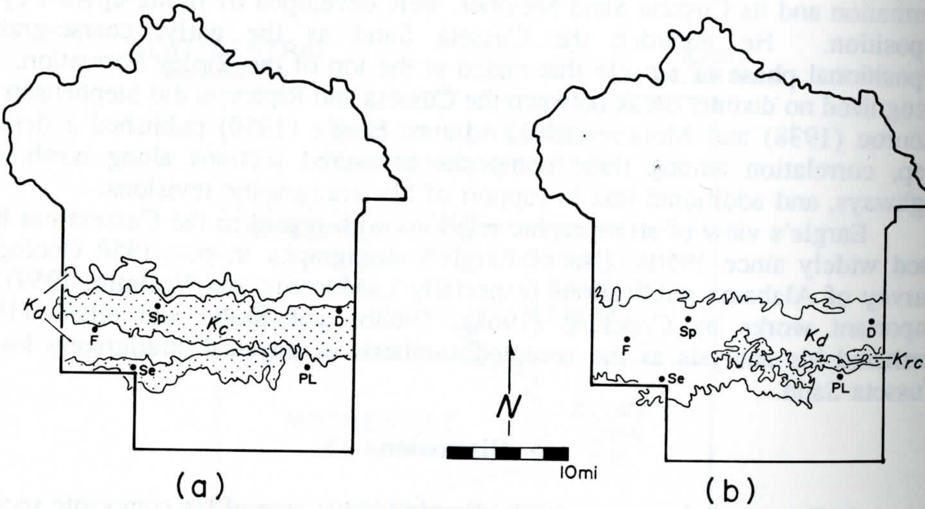

Figure 3. Geologic maps of interfingering Cusseta Sand and Demopolis Chalk in the transition zone, Montgomery County, Alabama. a) Map by Monroe (1941) showing relations of the Cusseta Sand (Kc, stippled) and the Demopolis Chalk (Kd). b) Map by Eargle (1950) showing relations of the Cusseta Sand Member of the Ripley Formation (Krc, stippled) and the Demopolis Chalk (Kd). Towns indicated: D = Downing, F = Fleta, PL = Pine Level, Se = Sellers, Sp = Sprague.

Another key difference between the stratigraphic synthesis of Monroe (1941) and Eargle (1950) is the depicted relationship of the Demopolis' upper tongue and the overlying Ripley Formation. According to Eargle's (1950) map, in a small area southwest of Pine Level, Montgomery County, Alabama, the

Demopolis and Ripley are at the same stratigraphic level. Eargle (1950) treats this relationship as a lateral gradation on his map and accompanying correlation. However, Monroe's (1941) map and correlation do not depict a lateral relationship between the Demopolis and Ripley. Further, Monroe (1941) shows a biostratigraphic zone boundary separating the Demopolis-Cusseta package from the overlying Ripley.

The nature of the upper boundary of the Cusseta is not described the same way by Monroe (1941) and Eargle (1948, 1950). While Monroe (1941) describes the contact as a correlatable disconformity distinguished by gravel deposits, Eargle (1955, p. 43) states that in Alabama the Cusseta is a member of the Ripley "because the boundary with the overlying (Ripley) is not distinct."

We have studied the area in detail and find that the physical relationships among the Ripley, Cusseta, and Demopolis and the lithic boundaries of the Cusseta are more nearly like those described by Monroe (1941). Unlike Eargle's stratigraphy, our stratigraphic data (to be presented in a subsequent section of this paper) shows a correlatable physical break or sharp facies discontinuity between the Cusseta and the Ripley and a lack of lateral facies relations between the Ripley and the Demopolis (as shown in Figure 2). Instead of lateral facies relations, our stratigraphic synthesis indicates a general westward thickening of the whole Cusseta-Demopolis package.

Revision of the Cusseta Sand

We recommend revision (without redefinition or complete redescription) of the Cusseta Sand Member of the Ripley Formation in order to raise the rank of the Cusseta once again to that of a formation in Alabama. According to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 854-855) revision includes changing a unit's rank while redefinition involves changing the descriptive term and redescription involves correction of inaccurate descriptions.

Our correlations and detailed study of the Cusseta Sand presented here cause us to raise its rank to a formation. Our reasons include the fact that the Cusseta is prevailingly tabular and is distinctive by its lithic character, bounding discontinuities, and stratigraphic position. All of the above are key elements in the definition of a formation in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 858). Eargle (1948) revised the Cusseta making it a member of the Ripley for reasons related to his interpreted fining-upward cyclic genesis of the Cusseta and Ripley. The Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 854) generally opposes such reasoning, stating that "genetic connotations, inferences regarding geologic history or specific environments of formation may play no proper role in the definition of a unit." Revision falls under the category of "definition of a unit" according to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 851).

We find it cumbersome that the Cusseta is regarded as the basal member of the Ripley Formation. The Ripley overlies both the Cusseta Sand and the Demopolis Chalk and the Cusseta grades laterally into the Demopolis (Figure 4). Further, the Cusseta is separated from the overlying Ripley Formation by a correlatable physical break (see facies discontinuity in Figure 4) that also separates the Demopolis and Ripley in western Alabama (Monroe, 1941; King, unpublished) and eastern Mississippi (Russell and others, 1983).

Perhaps because the current nomenclature is cumbersome, recent important studies of the stratigraphy and sedimentology of this part of the Coastal Plain use the name Cusseta Sand as a formation and do not mention its status as a member of the Ripley (Marsalis and Friddell, 1975; Sohl and Smith, 1980). In his Ph.D. dissertation, Hester (1968) states that "the Cusseta Sand is not the basal transgressive sand of the overlying Ripley Formation, but rather the Cusseta Sand is genetically related to the underlying Blufftown and Demopolis ..." Hester (1968) treated the Cusseta Sand as a continuous formation in both Alabama and Georgia. In a preliminary version of a forthcoming new geologic map of the eastern Alabama and western Georgia area, Reinhardt and Schindler (1986) use the Cusseta at the rank of formation in Alabama and Georgia.

As Reinhardt (1980) and Reinhardt and Donovan (1986) pointed out, the Cusseta still has formational status in Georgia. On the state geologic map of Georgia (Pickering and others, 1976), the Cusseta Sand is mapped as a formation as far east as the Flint River in Georgia where it passes laterally into "undifferentiated Upper Cretaceous strata."

We propose the objective descriptions presented in the following section as additional description of the Cusseta Sand augmenting those of Eargle (1948, 1950). We do not suggest use of our separate genetic interpretations as a basis for distinguishing the Cusseta Sand. As boundaries, we suggest retaining the Blufftown-Cusseta discontinuity ("basal conglomerate") described by Eargle (1950) and using the gravel layer along the Cusseta-Ripley discontinuity described by Monroe (1941) and observed this study. Our stratigraphic analysis shows that the Cusseta generally maintains its tabular character and grades laterally into the Demopolis Chalk of the Selma Group in central Alabama (Monroe, 1941; Hester, 1968; Braunstein and others, 1988). To the east, the Cusseta grades laterally into undifferentiated "post-Tuscaloosa and post-Middendorf Cretaceous" in central Georgia and into the subsurface Pine Key Formation in northern Florida (Carter and Wheeler, 1983; Braunstein and others, 1988).

FACIES ANALYSIS

Methods

A detailed stratigraphic study of the Cusseta Sand in Alabama, including the zone of transition with the Demopolis Chalk, was completed in order to understand the distribution of sedimentary facies within the Cusseta. More than 70 surface exposures of the Cusseta Sand, Demopolis Chalk, and Ripley Formation were measured and described, and many others were noted. The surface exposures consist of road cuts, creek banks, and sand pits. Surface exposures were relied upon exclusively for petrologic description. Subsurface data for the Cusseta is minimal; subsurface logs from three shallow wells are included in the stratigraphic cross-section presented in Figure 4.

The measured sections of the best surface exposures are the main source of data used in our stratigraphic cross-section correlation of the Cusseta Sand (Figure

4). This correlation was made by graphically projecting measured sections onto north-south dip lines (vertical lines in Figure 4). This technique has been used successfully by us for similar correlations in the underlying Blufftown Formation and Mooreville Chalk (Skotnicki and King, 1986; King, 1987a). In the correlation, relative stratigraphic positions of the measured sections were adjusted according to their basal elevation while compensating for a due south dip of 40 feet/mile. Driller's chip logs of three wells, described by Scott (1963), were used in the correlation diagram to add columnar sections of lithologic data (sections marked W on Figure 4). The contact of the Demopolis-Cusseta package with the underlying Mooreville-Blufftown package was used as the datum for the stratigraphic cross-section (Figure 4).

Sedimentary Facies in the Cusseta Sand

Field study of the Cusseta Sand outcrop in Alabama has delineated five general sedimentary facies. These facies are 1) an *Ophiomorpha*-bearing trough and planar cross-stratified sand, 2) an interlaminated fine sand and silty clay, 3) a bioturbated clayey fine sand, 4) a glauconitic siltstone, and 5) several thin hummocky cross-stratified sand beds which are interbedded with the glauconitic siltstone facies. Each facies is described and interpreted in separate sections below. The locations of typical exposures for each of the sedimentary facies are given in Appendix 1.

Facies 1 Description: This facies is an *Ophiomorpha*-bearing, medium- to coarse-grained sand that exhibits trough and planar cross-stratification and pebble lenses. The size of the cross-stratification varies within and among exposures but averages approximately one meter; cross-stratification is bipolar in several outcrops. Reactivation surfaces are common and clay clasts and clay drapes are commonly present above the reactivation surfaces. Clay clasts within the clay drapes suggest that the drapes likely originated from the ripped-up clay linings of common *Ophiomorpha*. This facies becomes distinctly bright red where deeply weathered.

Facies 1 Interpretation: We interpret this sedimentary facies by comparing it to previously studied facies in adjacent stratigraphic units. Facies 1 possesses textures, sedimentary structures, and biogenic structures that are nearly identical to interpreted barrier-island shoreface and tidal-inlet facies (Lerand, 1983; Kumar and Sanders, 1974). The main trace fossil, *Ophiomorpha*, is strongly associated with high energy shoreline sedimentation (Weimer and Hoyt, 1964). Well documented examples of this facies occur in the underlying Santonian Eutaw Formation (Reinhardt, 1980; Frazier and Taylor, 1980; Frazier, 1987) and the subjacent Campanian Blufftown Formation (Reinhardt and Gibson, 1980; Skotnicki and King, 1986). Hester (1968) describes a cross-bedded, *Ophiomorpha*-bearing facies in the Cusseta Sand of Georgia and Alabama and likewise interprets the deposits as barrier-island facies.

Facies 2 Description: This facies consists of alternating planar- and ripple-laminated fine-grained sand and homogenous silty clay. The thickness of each sand or clay lamina ranges from 0.5 to 3.0 cm. The sand and clay laminae are generally continuous across the outcrop (several meters), but the sand laminae may be discontinuous where isolated ripple structures (flaser bedding) occur. The sand and clay are both highly micaceous and the clay is slightly sandy at a few sites. At rare localities this facies gradationally overlies or underlies Facies 1 (Figure 4).

Facies 2 Interpretation: The textures and sedimentary structures within the alternating laminae of this facies and the stratigraphic relations of this facies with barrier-island facies (Facies 1) indicate variable, but overall less energetic conditions associated with a barrier island coast. A likely interpretation is back-barrier (lagoonal) deposition that is tidally influenced thus accounting for the common influxes of sand (Rampino and Sanders, 1980; Schwartz, 1982). In support of this interpretation, we note that sedimentary facies with nearly identical attributes situated in the subjacent Blufftown Formation have been interpreted to represent back-island deposition (Skotnicki and King, 1986).

Facies 3 Description: This facies is composed of micaceous, slightly glauconitic and very clayey fine-grained sand. The sediment is slightly calcareous; abundant secondary carbonate nodules produced by weathering occur on many outcrops. The sand lacks physical sedimentary structures and is highly bioturbated; *Thalassinoides* and *Teichichnus* are common ichnogenera. In general, this facies becomes more fine-grained and more calcareous toward the west where it passes into the calcareous clay and marl facies of the Demopolis Chalk (Kd in Figure 4).

Both articulated and disarticulated *Exogyra*, ranging up to 15 cm in diameter, are common in Facies 3. The articulated *Exogyra* occur most commonly in life position. Also common are shark and fish teeth, *Pinna*, ostreids, gastropods, *Baculites*, and *Gryphea*. In addition, several mosasaur (?) bones and bone fragments are present in one locality. In the upper 50 feet of the Cusseta (within Facies 3), *Flemingostrea* are common; their size and mode of occurrence is like that of *Exogyra* and they occur with the *Exogyra*.

Facies 3 Interpretation: The authors interpret this facies to have formed in a range of marine environments, lower-shoreface to inner-shelf, becoming generally more shelfal toward the west. This interpretation is made for two main reasons. First, this facies is situated laterally between the relatively coarse shoreline clastics of Facies 1 and 2 and the calcareous clay and marl of the Demopolis shelf facies (Figure 4; Demopolis facies described by King and others, 1988; Bittner and others, 1988). Second, there are analogous lower-shoreface and inner-shelf facies within the subjacent Blufftown Formation (in the transition zone between the Blufftown and the Mooreville Chalk in east-central Alabama; King and Skotnicki, 1986) and in Western Interior Seaway stratigraphy (Hancock, 1975; Rice, 1984). Further support for this interpretation is found in the fact that glauconitic fine clastics are generally common sediments of Cretaceous transgressive inner-shelf facies in many parts of the world (Jenkyns, 1980). In addition, a common shelfal association of sandy strata and ostreids along with the larger bivalves, e.g. *Exogyra*, suggests paleo-depths such as those noted above (Kauffman, 1967; Bottjer, 1981; Rice, 1984).

On the western side of the study area, Facies 3 comprises a Cusseta-Demopolis "transition zone" wherein the percent of silt and coarser clastic components gradually decreases toward the west. As discussed earlier, mapping in this transition zone has produced differing map interpretations in previous years. The amount of silt and coarser clastics in the transition zone was likely controlled by relative sea-level-dependent factors such as proximity to and availability of coastal clastic sources (Mount, 1984). Thus, the facies relations between the Cusseta and Demopolis at the limit of the "transition zone" most nearly track the history of relative sea-level change (discussed in a subsequent section).

Facies 4 Description: This facies consists of a highly micaceous, sandy glauconitic siltstone which is exposed principally in the Cowikee Prairie region of Barbour County and north of Pine Level in Montgomery County (locations noted in Figure 1). The glauconitic siltstone is highly bioturbated (but lacks distinct ichnogenera) and is commonly slightly fossiliferous. The most common fossils are ostreids, inoceramids, and shark teeth. Thin, sharp-based, comminuted-shell layers containing the above fossils occur in some exposures. Thin hummocky cross-stratified sand beds, discussed as a separate facies (Facies 5, described below), are intercalated with this facies in Cowikee Prairie exposures.

Facies 4 grades laterally into Facies 3 and is the lateral equivalent of Facies 3 in two different stratigraphic situations. As shown in Figure 4, Facies 4 occurs on both the east and west of Facies 3 at different levels (in different genetic packages, discussed later) in the stratigraphic cross-section.

Facies 4 Interpretation: The finer grain size and glauconitic character of Facies 4 versus Facies 3 suggests lower overall energy conditions for Facies 4. Therefore, where Facies 4 occurs on the western side of Facies 3 in the cross-section (upper 50 feet, Figure 4), Facies 4 is interpreted to represent slightly deeper shelf environments than those encompassed by Facies 3. This interpretation is consistent with the petrology of Facies 3 and the environmental interpretations given to similar deposits (Jenkyns, 1980; Skotnicki and King, 1986) and the fact that the western side is the more shelfward side of the stratigraphic cross-section (King, 1987a).

Where Facies 4 is situated on the eastern or shoreward side of Facies 3 in the stratigraphic cross-section (middle 150 feet, Figure 4), Facies 4 may represent sedimentation at depths comparable to those of Facies 3 but in an area that was relatively sand starved. Sand deprivation or redistribution on the shelf could be due to several factors including changing geostrophic currents (Rice and Shurr, 1983), development of minor physical barriers (Slatt, 1984), and autocyclic processes such as delta-lobe switching (Ryer, 1977; Winn and others, 1987). Excepting the latter hypothesis, for which no evidence of a Cusseta delta system exists in the study area, we cannot eliminate any hypothesis given previously while accounting for the available data. Hester (1968) also noted different glauconitic facies in the Cusseta of Georgia and Alabama. He was not able to distinguish clearly their paleobathymetry based on study of their macrofauna and planktonic/benthonic ratios, but considered the facies to be shallow marine in origin.

The intercalated hummocky cross-stratified sand beds (Facies 5, described below) are features typically formed by storm wave action, thus they are indicative of shelf paleobathymetry above storm wave base (Walker, 1985). Further, the sharp-based, autochthonous shell-fragment layers in Facies 4 likely formed by storm wave action (Rice, 1984) as well considering the fact that the fauna in these shell-fragment layers is the same as that in the non-scoured sediment (reasoning of Kreisa, 1981). These hummocky beds and shell layers do not indicate whether the water was deeper in the areas of Facies 4 deposition versus Facies 3. However, their presence indicates relatively high shelf sedimentation rates, thus accounting for the preservation of the hummocky cross-stratified sand beds and shell layers within highly bioturbated facies (Walker, 1985; King and others, 1988).

Facies 5 Description: This facies is composed of micaceous, fine-grained sand beds 2 to 10 cm thick. These sands commonly display hummocky cross-stratification and are laterally discontinuous. The sand beds occur within Facies 4, have sharp bases, and commonly possess a fine shell-hash component as a basal lag.

Facies 5 Interpretation: Facies 5 is interpreted to be a typical hummocky-bedded tempestite deposit which formed above storm wave base on the inner shelf (Dott and Bourgeois, 1982; Rice, 1984). Such storm deposits, with which the Cusseta beds compare very closely, are well documented in Cretaceous and other strata in many parts of the world (Walker, 1985). Hummocky cross-stratifed storm beds like Facies 5 have been described and correlated in the shelf facies of the subjacent Blufftown Formation in east-central Alabama (Skotnicki and King, 1986; King and Skotnicki, 1986) and in lagoonal facies of the Santonian Eutaw Formation in the Chattahoochee River valley area (Frazier and Taylor, 1980; Frazier, 1987).

Stratigraphic Correlation and Facies Relations

The correlation diagram (Figure 4) of main Cusseta Sand facies (Facies 1 - 4) shows facies relationships in the outcrop belt. This stratigraphic cross-section includes key surface exposures and three shallow water-well sections.

Figure 4 shows that the coarsest facies (Facies 1 and 2, representing barrier-island and back-barrier sedimentary environments, respectively) are situated exclusively in the eastern part of the study area. Specifically, these coarse-grained facies are located in the lower 125 to 190 feet and upper 30 to 50 feet of the formation (Figure 4). These Cusseta shoreline facies occur in the adjoining part of western Georgia as well (Hester, 1968).

The main fine-grained clastic facies (Facies 3 and 4) are developed in the whole Cusseta in the western part of the study area where they interfinger with the clay and marl facies of the Demopolis Chalk. In addition, these fine-grained facies occur in the middle Cusseta in the eastern end of the outcrop belt where they are developed between the Cusseta shoreline facies packages (Figure 4).

The apparent depositional-dip (east-west) relations of the four main Cusseta facies (Facies 1 - 4) and also a general east-to-west fining in grain size is well shown in the facies relations of the upper 30 to 50 feet of the Cusseta. This set of facies comprises a single coeval genetic package much like the facies described in

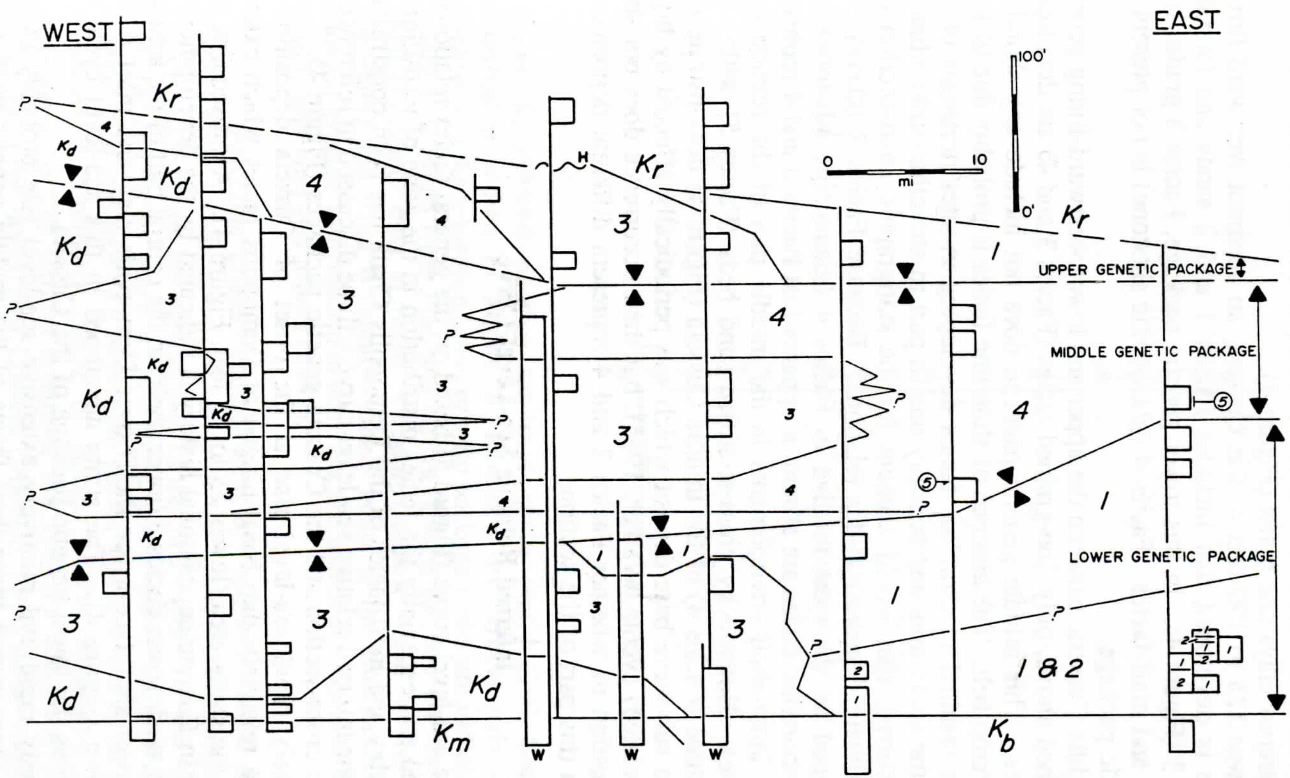

Figure 4. Stratigraphic cross-section showing relations of the main facies (1-4) from western Montgomery County to north-central Barbour County. Facies 5 is shown in two measured sections. Composite sections are constructed by projections based on basal elevations (method of King, 1987a). Genetic packages (see text) are indicated at right and their boundaries marked by opposing black triangles. Demopolis Chalk (clay and marl) facies are marked Kd. Formation abbreviations: Kr = Ripley Formation, Km = Mooreville Chalk, Kb = Blufftown Formation. W = Lithologic logs from shallow wells. H = hiatus at facies discontinuity, location from Monroe (1941).

the genetic packages of the underlying Blufftown Formation of eastern Alabama (Skotnicki and King, 1986). An east-to-west facies traverse in the upper genetic package of the Cusseta encompasses Facies 1 (barrier sands), Facies 3 (lower-shoreface to inner-shelf sands), Facies 4 (inner-shelf siltstones), and the Demopolis calcareous clays and marls (Figure 4).

In the lower 125 to 190 feet of the Cusseta, an apparent westward-fining genetic package is developed that includes Facies 1 and 2 sands and laterally adjacent Facies 3 (Figure 4). In this lower genetic package, Facies 3 grades into Demopolis clay and marl facies. Facies 4 (glauconitic siltstone) is not present in this lower genetic package.

In the middle Cusseta, between the upper and lower westward-fining genetic packages described above, only fine-grained facies (Facies 3 and 4) are developed in the study area. This middle genetic package does not include any shoreline facies in the outcrop belt. The absence of shoreline facies is probably due to sea-level rise which resulted in shoreline facies developing in sites northeast of the outcrop belt in the study area and possibly due in part to shoreline-strike change. If the latter occurred, that would account for the statigraphic cross-section not showing approximate depositional-dip relations. Because Facies 3 (clayey fine sand) is developed on the west relative to Facies 4 (glauconitic siltstone) and because coeval shoreline facies are absent, it appears that Facies 3 and 4 represent nearly identical inner-shelf environments in the middle part of the section (see discussion above). Hummocky cross-stratified sand beds (Facies 5) withi the glauconitic siltstone (Facies 4) of the middle Cusseta (Figure 4) demonstrate that the siltstone is a sub-wave base deposit which was periodically affected by high-energy (storm-related) events (Walker, 1985), but their occurrence does not shed light on the question of whether Facies 3 and 4 represent different depositional environments in this part of the section.

Inferred Relative Sea-Level Curve

A relative sea-level curve (Figure 5) based on the general facies relations of the Cusseta Sand and especially the facies distribution in the zone of transition to the calcareous clay and marl facies of the Demopolis Chalk has been constructed. In this section, the inferred relative sea-level curve will be discussed in reference to the stratigraphic cross-section and the Cusseta genetic packages (Figure 4).

A relatively rapid sea-level rise at the onset of Cusseta deposition is indicated by the relatively thin basal tongue of Demopolis facies which extends halfway across the study area (lower 25 to 75 feet, Figure 4). A subsequent sea-level drop early in Cusseta depositional history is indicated by the development of Facies 1 (barrier sands) over Facies 3 (inner shelf) in the central part of the area and by Facies 3 (lower shoreface-inner shelf) over Demopolis clay and marl (shelf) facies in the west (Figure 4). The strata developed in this sea-level cycle are described above as the lower genetic package of the Cusseta.

A relatively rapid and relatively extensive sea-level rise probably caused Facies 3 and 4 (two coeval inner-shelf facies of the middle genetic package) to develop across most of the area and resulted in Demopolis facies interfingering with Facies 3 in the west (between 175 and 250 feet above the base, Figure 4). The interfingering of the Demopolis facies with Facies 3 at two levels in the west may indicate small sea-level fluctuations superimposed on the main trend or changes in the rate of sediment input during the middle part of Cusseta depositional history (Figure 5).

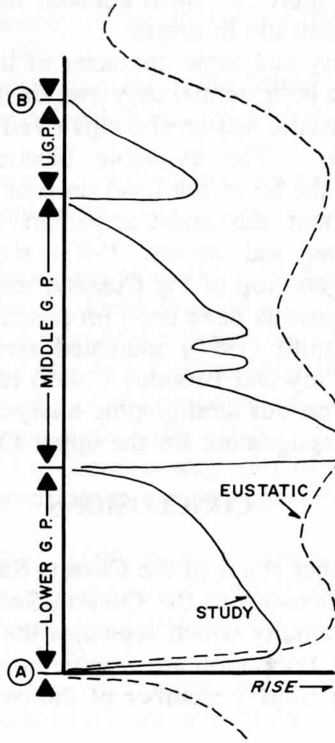

Figure 5. Inferred relative sea-level curve (solid line) based on the facies distribution shown in Figure 5. Distance on veritcal axis is proportional to thickness in the transition zone; genetic package limits are indicated. Eustatic curve (dashed) is taken from Haq and others (1987); the two curves are matched using biostratigraphic data at point A (approximately equal to the biozone NC18/19 boundary) and point B (approximately equal to the biozone NC19/20 boundary). Biostratigraphic information needed for the match are found in Smith and Mancini (1983) and Haq and others (1987).

A regressive phase occurred near the end of Cusseta deposition. In this phase, Facies 1 (barrier island sands of the upper genetic package) developed in and prograded from the eastern side of the study area. On the western side, coeval shelf facies (Facies 3 and 4) developed and likewise prograded (Figure 4). This progradation was part of a regressive period that ended with an episode of erosion. A facies discontinuity (term of King, 1987b) suggesting a notable hiatus attributable to this erosion separates the gravelly nearshore facies of the lower Ripley from the underlying Cusseta (Monroe, 1941; King, unpublished; Figure 5). This stratigraphic break is noted as far west as eastern Mississippi (Russell and others, 1983) where it is distinguished by concentrations of steinkerns and phosphatic clasts.

The correlation of the mid- to latest Campanian segment of the global eustatic sea-level curve (Haq and others, 1987) to the inferred Cusseta curve (using available biostratigraphic data in Smith and Mancini, 1983) shows a close match between the two curves (Figure 5). Such a match suggests to us that the Cusseta sea-level fluctuations are eustatic in origin.

The lateral continuity and lithic character of the stratigraphic breaks at the base and top of the Cusseta indicate that they owe their origin to significant (greater than 50 m) Cretaceous eustatic sea-level drops (Vail and others, 1987; King and Skotnicki, in preparation). The available biostratigraphic data (Smith and Mancini, 1983) show that the 65 m sea-level drop in the Campanian (age: 80 Ma; Haq and others, 1987) and the end-Campanian (74 Ma) sea-level drop of approximately 50 m (Haq and others, 1987) should be matched with the discontinuities at the base and top of the Cusseta, respectively.

Different age assignments have been proposed for the upper few meters of the Cusseta; Sohl and Smith (1980) indicated some evidence for an earliest Maastrichtian age, while Frey and Bromley (1985) regarded the upper Cusseta as latest Campanian. Based on our stratigraphic analysis presented above, we favor the latest Campanian age assignment for the upper Cusseta.

CONCLUSIONS

1) The current member status of the Cusseta Sand is cumbersome and needs revision. The lateral relationship of the Cusseta Sand and Demopolis Chalk and the sharp lithologic discontinuity which separates the Cusseta-Demopolis package from the overlying Ripley Formation are reasons to revise (raise the rank) of the Cusseta Sand in Alabama from a member of the overlying Ripley Formation to formation status.

2) The Cusseta Sand in Alabama consists of barrier-island (Facies 1), back-barrier (Facies 2), and inner-shelf (Facies 3, 4, and 5) deposits. Facies 3 comprises a broad "transition zone" of westward-fining shelfal strata which grade into the calcareous clay and marl facies of the Demopolis Chalk.

3) The Cusseta Sand was deposited during three cycles of eustatic sea-level rise and fall during mid- to latest Campanian.

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APPENDIX 1

Exemplary Localities of Cusseta Sand Facies

1. Trough and planar cross-stratified sand:

In Russell County, an exposure occurs on the eastern side of Russell County Hwy. 43, 2.0 miles northwest of the junction with Alabama Hwy. 165 (SE1/4, NW1/4, Sec. 18, T14N, R30E).

In Russell County, an exposure occurs on the north side of Russell County Hwy. 43, 1.8 miles northwest of the junction with Alabama Hwy. 165 (NW1/4, SW1/4, Sec. 18, T14N, R30E).

2. Interlaminated fine sand and silty clay:

In Russell County, an outcrop occurs on the west side of a dirt road leading north from Cottonton, 1.3 miles south of the junction with Russell County Hwy. 43 (NE1/4, NW1/4, Sec. 24, T14N, R29E).

In Bullock County, an outcrop occurs on the eastern side of a dirt road leading south from Enon, 1.0 mile south of the junction with Bullock County Hwy. 106 (NW1/4, NE1/4, Sec. 2, T13N, R25E).

3. Bioturbated clayey fine sand:

In Bullock County, many exposures occur on both sides of U.S. Hwy. 82, from the junction with Bullock County Hwy. 22 to the junction with Bullock County Hwy. 7.

In Bullock County, exposures occur on either side of U.S. Hwy. 82, 1.7 miles east of the junction with U.S. Hwy. 29 (NW1/4, NW1/4, Sec. 6, T13N, R24E).

4. Glauconitic siltstone:

In Montgomery County, an outcrop exists on the western side of U.S. Hwy. 231, 1.4 miles north of the junction with Montgomery County Hwy. 89 in the town of Pine Level (NW1/4, SE1/4, Sec. 21, T13N, R20E).

In Barbour County, an outcrop occurs in the banks of the Middle Fork of Cowikee Creek under the bridge on Barbour County Hwy. 97 (NE1/4, NW1/4, Sec. 18, T12N, R29E).

5. Thin hummocky cross-stratified sand beds:

In Barbour County, an exposure occurs in the banks of the Middle Fork of Cowikee Creek under the bridge on Barbour County Hwy. 97 (NE1/4, NW1/4, Sec. 18, T12N, R29E).

In Barbour County, an exposure occurs in the banks of the Middle Fork of Cowikee Creek under the bridge on the dirt road leading north from Barbour County Hwy. 89 (SE1/4, NE1/4, Sec. 4, T12N, R28E).